DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This thesis is dedicated to people who conserve biodiversity due to the passion they have for organisms.

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LIST OF ACRONYMS/ABBREVIATIONS

AEZ: Agro-Ecological Zone

Bd: Bulk Density

BS: Base Saturation

CAN: Calcium Ammonium Nitrate

CEC: Cation Exchange Capacity

DAP: Diammonium Phosphate

DMRT: Duncan's Multiple Range Test

DSP: Double Supper Phosphate

ECEC: Effective Cation Exchange Capacity

FAO: Food and Agriculture Organization

FURP: Fertilizer Use Recommendation Project

IUCN: International Union for Conservation of Nature

KARI: Kenya Agricultural Research Institute

LH: Lower Highland

LH: Lower highland

Masl: Meters above sea level

NA: Nutrient Agar

NPK: Nitrogen Phosphorus Potassium

PDA: Potato Dextrose Agar

SSP: Single Supper Phosphate

TSP: Triple Supper Phosphate

UM: Upper Midland

USDA: United State Development Authority

ABSTRACT

In Kenya, 10% (5.5 million hectares) are acid soils. Acid soils are prominent in upper midland zone 1 (UM_1) also referred to as tea zone. Kavutiri area in Embu County is composed of mainly small-scale farmers. Small-scale farmers often leave their land fallow when they became very unproductive. Kavutiri soils have overtime developed high acidity levels ranging between pH 4.2 and pH 4.6. Soil acidification disrupts biodiversity due to saturation and consequent toxicity of elements such as aluminum and manganese and unavailability of nutrients such as phosphorus, magnesium and calcium. Proper liming ameliorates soils by replenishing soil base cations and reducing soil acidity. However, the response of biodiversity to liming in Kavutiri was not known. There was therefore a need to investigate the impact of liming on biodiversity. This was done by characterizing the physical and chemical changes of acidic soil resulting from liming, established the frequencies of flora and fauna species resulting from soil liming and finally determining the relationship between soil liming and biodiversity in acid soil.

The site was identified within an area previously left fallow for two seasons in Kavutiri area, Embu County. Vegetation and debris on the land area measuring 32 m x 28 m were cleared. A randomized complete block design with four blocks and four treatments per block was laid out. The treatments comprised rates of lime which were as follows; 0 (L0), 2.4t/ha (L1), 6t/ha (L2) and 8t/ha (L3). The lime was applied mixed into 0-15 cm depth of soil. . Since lime react very slowly (Smith et al., 1994), five months reaction period was allowed. The plots were weeded in the 5^{th} and 11^{th}

week after treatments to simulate farmers practice. Plots were subsequently reserved for four months for colonization of flora and fauna. When applied at 2.4t/ha, 6t/ha and 8t/ha, the liming material increased the pH of the soil by 11.9%, 33.3% and 40.4%, respectively. After liming the Ca and Mg in the soil increased by 42.8% and 56%, respectively for lime rate 8t/ha while lime rate 6t/ha caused increase of 32.1% and 48% for Ca and Mg, respectively. Liming also lowered exchangeable Al^{3+} in the soil by 24% for 8t/ha and 22.7% for 6t/ha. Al and Mn reduced in the soil following logarithmic regression $R^2 = 0.867$ and $R^2 = 0.992$, respectively. On the other hand, Ca and Mg increased exponentially $R^2 = 0.956$ and $R^2 = 0.927$, respectively while phosphate had a polynomial increase in the soil $R^2 = 0.999$.

Biodiversity relationship with lime levels from the beginning of the experiment to nine months was polynomial with statistical regressions: L0 ($R^2 = 1$); L1 ($R^2 = 1$); L2 ($R^2 = 1$); L3 ($R^2 = 1$). The experiment revealed the existence of a relationship between biodiversity and soil liming in acid soils, the more the liming the more the biodiversity. 6t/ha and 8t/ha provided the highest biodiversity. Therefore, the 6t/ha should be used for increasing the diversity of flora and fauna.

A further study is required to explore more rates of lime and their effects on biodiversity to determine the optimum liming level for acid soils. The experiment was based on experimental scale of 4 m^2 per plot; it is recommended that a large landscape scale be explored to determine what would be the effect of liming on biodiversity.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Acid soils in Kenya

Acid soil refers to a soil with a pH equal or less than 5.5. In Kenya, 10% (5.5 million hectares) are acid soils (Mugai et al., 2008). Acid soils are prominent in upper midland zone 1 (UM_1) also referred to as tea zone (Jaetzold et al., 2006). High soil acidity causes suppression of many natural life forms mainly because of toxic levels of Al accompanied by fixed phosphate (Kanyanjua, 2002). This makes UM_1 ecology essential for biodiversity studies. UM_1 in Kenya have high numbers of small-scale farmers. Unilever Sustainable Agriculture Advisory Board (2003) estimated the population of small-scale farmers in UM_1 in Kenya to be 422,000 in 2003. Small-scale farmers often leave their land fallow when they became very unproductive (Gesimba, 2005). Fallow farmlands will be more useful to small-scale farmers if they can support higher biodiversity, because such lands can provide human food and fodder (Black and Okwakol, 1997). Whereas suppressing biodiversity is generally not beneficial to all human beings ecologically, small-scale farmers lose out most when biodiversity is heavily inhibited (Maneepitak, 2007). Kenya ratified biodiversity treaty and in doing so it became committed to biodiversity conservation in all practices including farming (Gaston and Spicer, 2004). Soil management practices that focus on reducing soil acidity are rare in small-scale farming (Kirambi, 2008). Acid soil is unfavorable to flora and fauna diversity (Susan and Fahrig, 1995). Fortunately, liming has been found to ameliorate acid soils (Mugai et al., 2008).

However, the impact of liming on diversity of flora and fauna in acid soil requires to be studied.

1.1.1 Embu acid soil

Acid soils in Embu County of Kenya are mainly found in Embu tea zone. According to Jaetzold et al., (2006), Embu tea zone is ecologically defined by lower highland zone (LH_1) and Upper mid-land zone (UM_1). It shows the typical agro-ecological profile of the windward side of Mt. Kenya of the cold and wet upper zones. The average annual rainfall is 1700 mm and 1800 mm for UM_2 and LH_1 consecutively (Ouma et al., 2002). The soils are mainly acidic with thick humic topsoil (FURP, 1988). Kavutiri area in Gaturi location is a typical example of an area with acidic soils in Embu tea zone (Kanyanjua, 2002). Originally, before 1962, these soils were characterized by high nutrient availability that supported farming of food crops without addition of any fertilizers (Mutsotso, 2005). Such crops included maize, arrowroots, bananas, yams, beans, sorghum, cassava and sweet potatoes.

According to Mutsotso (2005), the harvests from food crops started to decline sharply in 1966 and farmers had to intensify farming. Farmers started relying on agrochemicals to realize impressive crop harvests, a practice that continues to date. The commonly used fertilizers are NPK, CAN, Urea, DAP, TSP, SSP and DSP while the fungicides are Cobox®, Green coppers®, Mealraz®, Reval meal® and Cupro® Cuffallo®. The common insecticides are Dimethoite®, Dusbarn®, Karate® and Brigade® (Mutsotso, 2005). The most remarkable phenomenon in Embu tea zone however, has been the decline in biodiversity (Mutsotso, 2005).

1.1.2 Kavutiri

Kavutiri occupies an Upper midland zone (UM_1) that is Tea/Dairy/Coffee zones (Ouma et al., 2002). The soils are ando-humic Nitisols derived from olivine basalts and nepherine phonolites, which compose the tertiary basic rocks parent material (FAO-UNESCO, 1974). According to USDA Soil Taxonomy (1975), the soil is classified as orthoxic Palehumult. The soil is well drained with relatively high organic carbon and deep clayey subsurface layer, hard when dry, friable when moist and sticky when wet. Iron and manganese concretions are visible in some occasions.

The agricultural practices are mainly cash and food crop farming as well as dairy farming. The area is composed of mainly small-scale farmers with estimated farmholding of 0.4 - 0.8 ha (Kirambi, 2008). Farmers produce mainly tea and coffee as cash crops and other crops such as maize, bananas, beans, arrowroots, yams, Irish and sweet potatoes for subsistence purposes, and kept dairy animals. When the cash crops returns become too low, some farmers cut down tea or coffee bushes and replace them with other crops (Ombuki, 2004).

1.2 The main sources of acidity

Acidic soil is one that has abundance of acidic cations like hydrogen (H^+) compared to hydroxyl (OH^-) (Douglas and Lingenfelter, 1995). Usually acid soils are rich in cations such as Al, Fe, and Mn which have low logarithmic acid dissociation constant (p*K*a) while alkaline ones are rich in alkali earth elements like Ca, Mg and K. Strongly acidic soils suffer from reduced biodiversity (Slattery and Hollier, 2002). Some factors that are known to contribute to soil acidity were evident in Kavutiri.

Such factors included: excessive rainfall and leaching, crop cultivation, mineral fertilizers and aluminum reactions.

1.2.1 Strategies of reducing acidity

The effects of acidity can be reduced through application fertilizers rich in phosphate and Mg or Ca. This is more applicable for crops since fertilizer is applied in the seed holes. However, biodiversity spread throughout the farmland and broadcasting fertilizer would be complicated and very expensive for a farmer (Mugai et al., 2008). Lime therefore provides the simplest and more reliable method for reducing acidity.

1.3 Biodiversity definition

The term biodiversity evolved in late 1980s and was originally used to mean biological diversity (Delong, 1996). Presently, a widely used definition is that included within the Convention on Biological Diversity (CBD). CBD defines biodiversity as “the variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. All encompassing definitions have however complicated the use of the term biodiversity. According to Wordweb dictionary, biodiversity is defined as the variety of plant and animal life in a particular habitat. In this study, the meaning takes an ecological perspective, which means it considers an area dimension. Thus, it refers to variety of naturally occurring organisms in an area (Millennium Ecosystem Assessment biodiversity, 2005).

1.4 Importance of biodiversity

Like in other parts of the world, Kavutiri people cannot exist without biodiversity since it is used in all aspects of lives. The use is either directly and indirectly. Direct use include food, fibres, medicines and fodder, whilst indirect uses included ecosystem services such as atmospheric regulation, nutrient cycling and pollination (Mutsotso, 2005). It has been noted that biodiversity has non-use values such as option value (for future use or non-use), bequest value (in passing on a resource to future generations), existence value (value to people irrespective of use or non-use) and intrinsic value (inherent worth, independent of that placed upon it by humans) (Gaston and Spicer 2004). Kenya signed biodiversity treaty at the United Nations Conference on Environment and Development, held in Rio de Janeiro, Brazil, in June 1992. It later ratified it in July 1997. This strengthens the importance of the biodiversity in all parts of the country.

Many of the uses of biodiversity are not incorporated in economic accounts and this leads humans to under-value biodiversity (Kevin, 2007). Ecosystem services and resources in Kavutiri such as soil nutrients, and genetic resources are capital assets but traditional national accounts do not include measures of the depletion of these resources. This means Kavutiri people could cut their indigenous plants and deplete soil nutrients through over cultivation, and this would show only as a positive gain in GDP (gross national product) without registering the corresponding decline in assets (MEA 2005).

Biodiversity is often used as a measure of the health of biological systems (Turner et al., 2003). Biodiversity provides sustainable production of food, biological support to

production, and ecosystem services, thus it is the foundation of farming (UKabc, 2000). Biodiversity Education and Awareness Network (BEAN), (2009) noted that high biodiversity leads to greater productivity in plant communities. BEAN also pointed that high biodiversity reduces the relative size of seasonal change productivity fluctuations, leads to greater nutrient retention in ecosystems and leads to greater ecosystem stability (i.e. returns quickly to an equilibrium in case of a disturbance). According to BEAN, ecosystem processes are less stable or reliable at lower diversity levels but high diversity leads to greater resistance to invasion and diseases. Reducing biodiversity lowers landscape aesthetic value (Rolston, 1998). It is therefore necessary to encourage high biodiversity.

1.5 Effects of acidity on biodiversity

Soil acidification changes the natural habitat of many organisms favoring only few that have capacity to exist in acidity conditions (Susan and Fahrig, 1995). Georgina et al., (2005) noted that acidity mainly leads to increased levels of aluminum and manganese available to the plant, causing toxicity damage to sensitive flora and fauna. Soil acidity may lead to: poor plant establishment and persistence; patchy or uneven organisms growth in an area, reduced nodulation in legumes, and increased susceptibility of organisms to diseases, yellowing or necrotic (dead) tips on leaves of plants and short or stunted root growth.

1.6 Effect of liming on acidity and biodiversity

Problems such as low yields and slow plants growth associated with high acidity and P deficiency in Kenya have already been noted (Warren and Kihanda, 2001; Mugai

et al., 2008). High Al^{3+} concentration is toxic to Al sensitive plants where it inhibits the root elongation (Yamamoto et al., 2006). Phosphorus deficiency arises when Al^{3+} or Fe^{3+} bind with orthophosphate ions ($H_2PO_4^-$ and HPO_4^{-2}) forming insoluble compounds (Kanyanjua, 2002), which results in low levels of available phosphorus. Proper liming ameliorates soils by replenishing soil base cations and reducing soil acidity (Mitchell, 1999). Liming significantly reduces soil acidity and it is imperative to explore whether it will impact positively on biodiversity as well.

Overliming may lead to the formation of complexes especially of P with Ca or Mg. It can also increase pH causing molybdenum to become toxic (Douglas and Lingenfelter, 1995). In addition, nutrients such as copper, zinc, boron, and manganese can become deficient (Harter, 2007), disturbing the biodiversity. Just like non-liming in acid soils, overliming can equally pose enough dangers to disrupt biodiversity. Therefore, lime levels need to be evaluated to establish the relationship between soil liming and biodiversity in acid soils.

1.7 Problem statement

In the previous experiment in Kavutiri, it was noted that the pH ranged from pH 4.2 to pH 4.6, and aluminum levels were high enough to fix phosphate in the soils (Warren and Kihanda, 2001). KARI obtained similar findings in the same area and recommended that affordable and sustainable methods of amending these acidic soils needed to be developed (Kanyanjua, 2002). Whereas lime is recommended as an appropriate acid soils amendment material in Kenya (Warren and Kihanda, 2001), the appropriate amount of lime that could effectively reduce acidity and release fixed phosphate in Kavutiri basing on field trials had not been established.

The reduction in biodiversity accompanied by lack of proper measures to mitigate the reduction is another problem in Kavutiri. Mutsotso (2005) noted that the aggressive farming in Embu farmlands that started in 1966, with an objective of increasing the yield, was not accompanied by proper measures to conserve biodiversity. The concern on reduction of biodiversity in acid soils has created interest to find out more about biodiversity conservation measures (Susan and Fahrig, 1995). Reduction in biodiversity is a problem because with time it interferes with harmonious relationship within the flora and fauna, hence contributing to food insecurity (Black and Okwakol, 1997). Liming has been found to ameliorate acid soils (Kanyanjua, 2002; Warren and Kihanda, 2001), but has not been characterized for biodiversity. It is therefore paramount to establish the relationship between soil liming and biodiversity.

1.8 Justification

Limestone contains high content of calcium and magnesium carbonates. Its application in the soil initiates hydrolysis of carbonates producing hydroxyl ions hence reducing acidity. Lime material provide cations (Ca and Mg), hence benefiting the plants. It also facilitates the release of fixed phosphate making it available to the roots and help fixing Al cations hence reducing their toxicity in the roots, which could be beneficial to farmers. Toxic cations are the main cause of lower biodiversity in acidic soils (Smaling, 1993). Therefore, this simple method (liming) could have a great potential in mitigating the reduction of biodiversity in acid soils. Furthermore, liming is a simple technique that farmers can easily understand and apply. Since liming comes with other benefits such as amelioration of acidic soils, it will most

likely improve the farmers' yields, perhaps raising prospects of higher acceptability of this method by farmers. Carrying out biodiversity research project within Kavutiri farms is not only in line with the nation agenda arising from 1992 summit on biodiversity conservation, but also sensitizes farmers on its importance, and hence its conservation. This study experiments different levels of lime in acid soil to establish the relationship between soil liming and biodiversity, which had not been determined before. The experiment has a potential to add value to soil liming if it can raise biodiversity.

1.9 General objective

To investigate the impact of liming on biodiversity in acid soil of fallow farmland in Kavutiri, Embu County.

1.9.1 Specific objectives

i) To characterize the physical and chemical changes resulting from liming of acid fallow farmland soil.

ii) To establish the frequencies of flora and micro fauna species resulting from liming of acid soil.

iii) To determine the relationship between soil liming and, plant and micro fauna species composition for acid farmland soil.

1.9.2 Null Hypothesis

i) No physical and chemical properties changes due to liming of acid soil.

ii) No frequencies of flora and fauna species resulting from soil liming.

iii) No relationship between soil liming and biodiversity in acid soil.

1.9.3 Expected output

Liming was expected to reduce acidity, raise Ca, Mg, P and result in higher frequencies of flora and fauna. A positive relationship between liming of acid soil and biodiversity was also expected.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Biodiversity

Biodiversity consists of a variety of below ground organisms, also called soil organisms, and above ground organisms. Soil organisms spend almost or all part of their life within the soil while above ground organisms spend almost or all part of their life above the soil (Krzic et al., 2004).

According to Department of Crop and Soil Sciences, (2004) soil organisms mainly consist of bacteria, fungi, actinomycetes, nematodes, protozoa, arthropods, earthworms and plant roots. Bacteria and fungi, make up 75-90% of the soil living biomass (Department of Crop and Soil Sciences, 2004). Several criteria can be used to classify soil organisms. Table 1 shows that according to size soil organisms can be classified into three types. These are macro, meso and microorganisms.

Table 1: Classification of soil organisms by size

Type	**Size**
Macro-organisms	(> 2 mm in width)
Meso-organisms	(0.2 to 2 mm in width)
Micro-organisms	(< 0.2 mm in width)

Source; Krzic et al., 2004

Another classification of soil organisms is on the basis of how they derive their food; heterotrophs that rely on organic compounds for their carbon and energy needs, and autotrophs that obtain their carbon mainly from CO_2 and their energy from

photosynthesis (phototrophs) or oxidation of various elements (chemotrophs) (Department of Crop and Soil Sciences, 2004).

2.1.1 Importance of soil organisms

Heterotrophic organisms transform organic molecules into mineral nutrients (e.g. nitrate, ammonium, phosphate) that are then available for uptake by plants (Boyer and Mahaney, 1985). The single cell animals such as protozoa and nematodes (simple worms), prey on the microbes (USDA, 1999). The mesoorganisms group of collembola and mites prey on bacteria and fungi. The larger organisms or macro fauna include earthworms, beetles, ants and termites (Boyer and Mahaney, 1985). Soil organisms decompose organic matter making it plants nutrients. They also help in distributing nutrients throughout the root zone. Table 2 summarizes the various roles of soil organisms and their estimated quantities in the soil.

Table 2: Soil biotic components, roles and estimated quantities in tropical soils

Biotic soil components	Typical number or length (in one handful of soil)	Typical biomass (pounds/acre)
Plants Plant residues (both roots and shoots) are the ultimate source of almost all carbon (energy) for soil organisms. There may be 1,000 times more soil microorganisms near plant roots than in soil further away from roots.	60 – 150 inches (annual plants) 1,500 – 3,000 inches (perennial grasses)	3,000 (annual plants) 15,000 (perennial grasses)
Bacteria Along with fungi, these are the most important group in organic matter decomposition. Extracellular compounds help bind soil particles into aggregates. Specialized groups are involved in each portion of the nitrogen cycle	300 million – 50 billion	400 – 4,000
Fungi The most important group involved in decomposing resistant compounds such as lignin. Hyphae grow extensively through soils, helping bind soil particles in aggregates. Some specialized fungi grow symbiotically with plant roots, increasing nutrient and water uptake and decreasing disease incidence	500,000 – 100 million	500 – 5,000
Actinomycetes These are types of bacteria with growth forms similar to fungi but functions are similar to both. They produce compounds that give soil its distinctive aroma.	100 million – 2 billion	400 – 4,000
Nematodes These are the most numerous animals in the soil. Help accelerate decomposition when they graze on plant residues.	1,000 – 10,000	5 – 50
Protozoa They help accelerate decomposition when they graze on plant residues.	100,000 – 50 million	5 – 100

Table 2 continues

Arthropods Help accelerate decomposition when they (mites, collembolan and other insects) graze on plant residues.	100 – 1,000	1 – 10
Earthworms Burrowing activity mixes soils and creates macropores that increase water infiltration and flow, help aerate soil and decrease soil bulk density. Soil passage through guts increases aggregation and nutrient cycling.	0 – 2	10 – 40

Source: Department of Crop and Soil Sciences; Michigan State University, 2004

2.1.2 Liming and soil organisms interactions

It is widely known that soil acidity limits the growth of many soil organisms. Liming substantially improves soil organisms' populations (Helyar et al, 1994; 1997). The micro-fauna such as bacteria (rhizobia species) associated with nitrification (conversion of NH_4^+ to NO_3^-), require calcium to perform the conversion efficiently. Unfortunately, in very acidic soils Ca is not readily available. Hence, rhizobia species benefit from liming which supply Ca (Douglas and Lingenfelter, 1995). Macro-fauna such as earthworms, beetles and ants feed on lime and in the process increase aeration hence improving the quality of the soil for plant growth (Department of Crop and Soil Sciences, 2004). According to Boyer and Mahaney, (1985), soil organisms help in distributing lime material throughout the soils. This means nutrients associated with lime such as Ca and Mg are availed to the plants roots making them more beneficial to the flora community.

2.1.3 Importance of above ground organisms

Above ground organisms spend all or most part of their lives outside the soil. These organisms range from single cell organisms to huge mammals. It is therefore extremely difficult to evaluate above ground organisms without defining the spatial scale of interest (Gross et al., 2000). A spatial scale of 4 x 4 m^2 for example will largely allow evaluation of arthropods, herbaceous vegetation, reptiles (<1m) and mammals (<1m). In agricultural landscapes, a spatial scale of 4 x 4 m^2 is suitable for evaluation of arthropods and herbaceous plants (Gross et al., 2000). Above ground organisms are important because they give the first impression of biodiversity in an area. Vegetation serves as a habitat for most arthropods. In Kavutiri area, vegetation is mainly slashed for fodder and to pave way for cultivation. Occasionally, farmers use herbicides to eradicate weeds from their farms. Gillison, (2000) noted that habitat loss is the main factor associated with above ground biodiversity decline and it increases with intensive, permanent, large-area cropping systems.

2.2 Soil physical and chemical properties in acidic soils

Acidic soils have low basic cations such as Ca^{2+} and Mg^{2+} and high H^{+} in the exchange sites, hence low soil pH in soil solution (Mitchell, 1999). The aluminum cations (Al^{3+}) are high due to low pH (Mugai et al., 2008). In acidic soils, there is more aggregation breakdown by raindrop impact, surface crusting, soil swelling, surface runoff and surface water erosion (Aura, 2005). The pH scale ranges from 0 to 14. As the amount of hydrogen ions in the soil increases, the soil pH decreases, thus becoming more acidic (Ross, 2003). From pH 7 to 0, the soil is increasingly more acidic (Table 3), and from pH 7 to 14, the soil is increasingly more alkaline or basic.

Table 3: Most common classes of soil pH

pH range	Interpretation
3.5 – 4.4	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 – 6.0	Moderately acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Slightly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9	Strongly alkaline

Source: USDA, 1999.

It is difficult to know the exact cause of acidity in Embu tea zone. However, some factors that are known to cause acidity have been noted in Embu tea zone. These are aluminum reactions, mineral fertilizers, crop cultivation, excessive rainfall and leaching.

2.2.1 Aluminum reactions

Aluminum (Al^{3+}) is a frequently available element in Kavutiri soils due to the nature of parent rock (Warren and Kihanda, 2001). Acidity come from H^+ ions that are released when high levels of Al^{3+} in the soil react with water molecules (Douglas and Lingenfelter, 1995).

$$Al^{3+} + 3H_2O \longrightarrow Al(OH)_3 + 3H^+$$

2.2.2 Mineral fertilizers

Kavutiri farmers access mineral fertilizers very easily by purchasing them from the shops. The tea factory in the area (Mungania tea factory) also supplies ammonium-containing fertilizers as they focus on maximization of the tea leaves production. CAN, DAP and urea are among the most commonly used fertilizers in food crops. Food crops have no standard measure for fertilizer due to small farm sizes and lack of proper services. When ammonium (NH_4^+) containing fertilizers are applied to the soil, they release hydrogen ions upon nitrification hence lowering the soil pH. NH_4^+ reacts with oxygen through enzymic reaction of nitrifying bacteria to release nitrite, hydrogen protons and water (Mitchell, 1999). Ammonium ions (NH_4^+) in the soil solution exist in equilibrium with ammonia gas (NH_3). The equilibrium is strongly pH dependent. The difference between NH_3 and NH_4^+ is an H^+. For example, if NH_4^+ were applied to the soil at pH 7, the equilibrium condition would be 99% NH_4^+ and 1% NH_3. At pH 8, approximately 10% would exist as NH_3 (Ross, 2003).

The following equations show nitrification chemistry.

i) $2NH_4^+ + {}^5/_2O_2 \xrightarrow{\textit{Nitrosomonas}} NO_2^- + NO_2 + 2H^+ + H_2O + 2e^-$

ii) $NO_2^- + {}^1/_2O_2 \xrightarrow{\textit{Nitrobacter}} NO_3^- + e^-$

The resulting H^+ from (i) in the soil then lowers the pH.

2.2.3 Crop cultivation

Crop cultivation commonly induces soil acidity in intensively cultivated lands (Mitchell, 1999). Gordon (1999) observed that harvesting of crops has its effect on

soil acidity development, because plants absorb higher pK_a cations for their nutrition. When these plants are harvested and the biomass is removed from the field, some of the basic material responsible for counteracting the acidity developed by other processes is lost, and the net effect is increased soil acidity. Plant roots excrete H^+ in exchange of the basic cation uptake (Mitchell, 1999). These H^+ exudates are also responsible for low pH in intensively cultivated lands. Increasing crop yields accompanied by removal of plant remains from the farm depletes greater amounts of basic elements. After harvesting crops such as maize, farmers cut the residues and use them to feed dairy animals (Mutsotso, 2005). Although they later add animal compost to the farms, the nutrients returns is too low and does not balance out with the depleted cations (Ouma et al., 2002).

2.2.4 Excessive rainfall and leaching

Kavutiri is a high altitude area with relatively high rainfall of 1730mm per annum. Scientists have noted that excess rainfall dissolves base cations such as Ca and Mg and leach them to deeper layers or erode them into rivers, depositing them away from the reach of many crop roots (Gordon, 1999). The released low pK_a cations like Al and Fe react with water and persist on soil as hydroxides. Hence, this source of acidity is also likely in Kavutiri soils.

2.3 Role of acidity on fauna

Acidic soils permit the release of ions such as aluminum, manganese and iron ions that can harm microorganisms and plants in the soil. Soil acidification could induce permanent reductions for earthworm casting (Baker et al., 1996). Van Gestel and

Hoogerwerf (2001) found that when 1000 mg of aluminum was added to 1 kg of artificial soil at pH 4.3, aluminum became toxic to earthworms and significantly reduced their growth and cocoon production while at pH 3.5 all earthworms died. In high acid soils, macrofauna such as earthworms and beetles feed on soils with toxic levels of aluminum and manganese and their frequencies are significantly reduced (Anita, 2010). When mammals higher in the food chain such as birds feed on earthworms in highly acid soils, they pick up metals such as aluminum and manganese, which may also harm them (Anita, 2010). The most sensitive groups include fish, lichens, mosses, certain fungi and small aquatic organisms. It has been observed from other places in the world that heavy acidification of soils has already brought about substantial changes in biodiversity (Anita, 2010). Acid soils reduce biodiversity significantly, since very few biotic (plants and animals) survive under such conditions (Anita, 2010). The reason for this is that most soil organisms eat a carbon-based food source, which provides all their nutrients, including nitrogen and phosphorus (Hollier and Reid, 2005). Therefore, when acidity makes some nutrients unavailable, the soil organisms become malnourished. Boyer and Mahaney (1985), noted that an increase in the proportion of hydrogen ions in the soil (low pH), affected aspects of micro organisms life such as bacterial than meso organism such as nematodes. The electrochemical gradient, or difference in proportion and charge of ions between the inside and outside of the cell, is altered. This affects the ability of the cell to produce energy as well as some forms of solute transport.

Acidic soils cause death of useful microorganisms present in tree roots and reduce the rate at which soil organisms respire (Douglas and Lingenfelter, 1995). Aluminum

ions released from the soil may damage plant roots severely enough to cause the death of sensitive plant species (Anita, 2010). This reduces the plants diversity. The ideal range for most organisms is pH (water) of 5-8 (Anita, 2010).

2.4 Role of acidity and alkalinity on availability of nutrients in plants

When soil is acidic, essential nutrients such as Ca and Mg become deficient due to leaching (Marschner, 1995). When the soil pH is above 5.5, aluminum in the soil remains in a hydroxide form and is not harmful to plants. As the soil becames acidic, aluminum hydroxides begin to dissolve (Mitchell, 1999) posing significant danger to plants. Because of its nature as a cation (Al^{3+}), the amount of dissolved aluminum is 1000 times greater at pH 4.5 than at 5.5, and 1000 times greater at 3.5 than at 4.5 (Gordon, 1999). For this reason, some plants may seem to do very well, but then fail completely with just a small change in soil pH. Wheat, for example, may do well even at pH 5.0, but usually will fail completely at a pH of 4.0 (Gordon, 1999). Toxic levels of aluminum harm the plant by "root pruning" (Yamamoto et al., 2006). This means, a small amount of aluminum in the soil solution in excess of what is normal can cause the roots of most plants to either deteriorate or stop growing. As a result, the plants are unable to absorb water and nutrients normally and will appear stunted and exhibit nutrient deficiency symptoms (Gordon, 1999).

The relationship between acidity and dissolved manganese in the soil is similar to that for aluminum, except that manganese (Mn^{2+}) only increases 100 fold when the pH drops from 5.0 to 4.0. Toxic levels of manganese interfere with the normal growth processes of the plant parts (Mitchell, 1999). This usually results in stunted,

discolored plant growth. Fig. 1 shows effect of pH on nutrients availability for plant uptake.

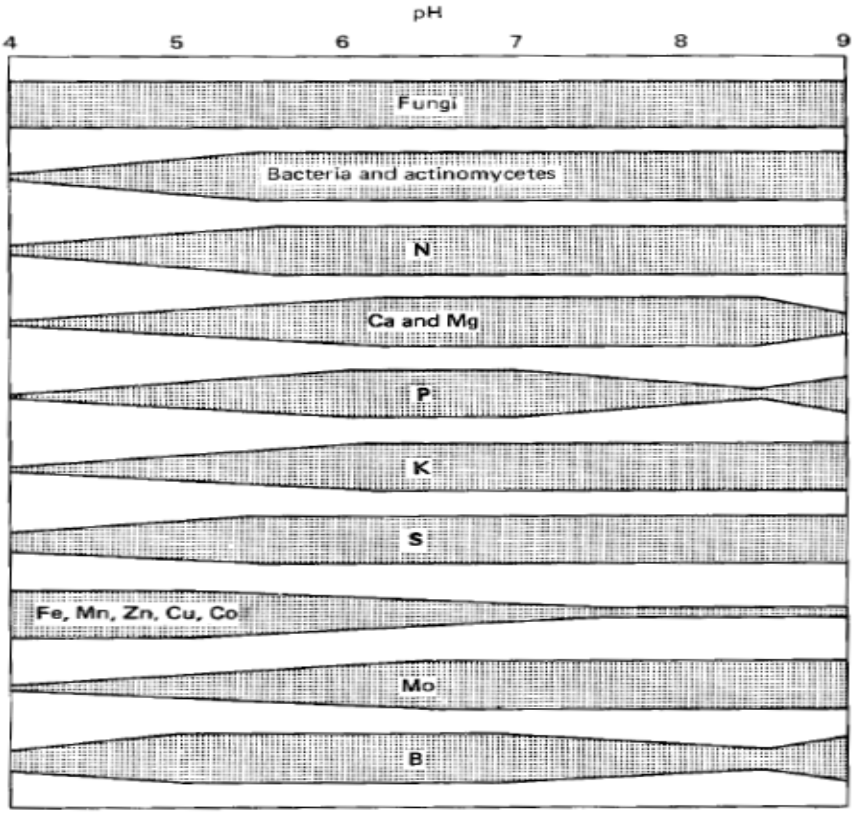


Figure 1: Effect of pH on nutrients and microorganisms availability for plant uptake. Source: Douglas and Lingenfelter, (1995)

Table 4 shows the summary of the effects of soil pH on mineral elements to plants. Availability of phosphorus is mainly dependent upon the pH of the soil. In acid soils, P forms complex compounds with iron and aluminum while in alkaline soils it forms complexes with calcium.

Table 4: Soil pH effects on mineral elements to plants

Problems in very acid soils	Problems in alkaline soils
Aluminum toxicity to plant roots	Iron deficiency
Manganese toxicity to plants	Manganese deficiency
Calcium and magnesium deficiency	Zinc deficiencies
Molybdenum deficiency in legumes	Excess salts (in some soils)
P tied up by Fe and Al	P tied up by Ca and Mg
Poor bacterial growth	Bacterial diseases in potatoes
Reduced nitrogen transformations	

Source: Mitchell, 1999

High concentrations of Al, Fe and Ca will result in the fixation of phosphorus in the soil and unavailable to the crop. Iron deficiency is more likely to occur in high pH soils. Molybdenum deficiency is most likely to occur in acid soils (Gordon, 1999). At low pH the solubility of boron is high while for molybdenum is low.

In alkaline soils of pH 7.8 or more, Ca and Mg are abundant because of the less dissolution of their compounds. High pH soils may have an inadequate availability of iron, manganese, copper, zinc and phosphorus. The later forms complexes especially with Ca or Mg (Douglas and Lingenfelter, 1995).

2.5 Soil physical and chemical changes resulting from soil liming

Soil acidity causes disturbances in properties and processes that lead to soil degradation and decline in quality (Smith et al., 1994). Acidification alters soil physical and chemical properties (Marschner, 1995). The practice of correcting soil acidity reduces the available contents of Al, Fe, Mn, and Zn but increases the availability of other essential nutrients (Gordon, 1999). Liming is an effective and

dominant practice to raise soil pH and reduce acidity-related constraints to improve crop yields (Mitchell, 1999). The quantity of lime required depends on the soil type, quality of liming material, costs and plant species or cultivars (Douglas and Lingenfelter, 1995).

2.5.1 Liming material and composition

There are various forms of liming materials, including dolomite, marl, chalk, limestone, or hydrated lime (Douglas and Lingenfelter, 1995). They contain magnesium or calcium that are animal and plant nutrients. Dolomitic limestone is one of the most commonly available liming materials in Kenya. According to Brett et al. (2005), ideal dolomite has a crystal lattice consisting of alternating layers of Ca and Mg, separated by layers of carbonates and calcium and magnesium are present in equal proportions. Dolomitic limestone is a type of limestone that contains dolomite, a crystalline mineral that contains calcium magnesium carbonate ($CaMg(CO_3)_2$). Plate 1 shows limestone deposits along Athi river in Kenya. When processed into dolomitic lime, this mineral becomes a white or gray to pink powder that is used in agriculture, gardening and lawn care to reduce the acidity of soil (Brett et al. 2005). The extent to which a given amount of lime per unit of soil volume will increase soil pH depends on the cation exchange capacity (CEC) of the soil and the acidity neutralizing effect of the lime (Brett et al. 2005). Soils with low CEC will show a more marked pH increase than soils with high CEC.

Plate 1: Limestone deposits along Athi river, Kenya
Source: Author.

However, the low-CEC soils will experience more rapid leaching of the added bases, and so will see a quicker return to original acidity unless additional liming is done (Tagwira et al, 1992).

2.5.2 Benefits of liming

According to Douglas and Lingenfelter, (1995), liming reduces the possibility of Mn^{2+}, Al^{3+}, Fe^{3+} as well as Zn and Cu toxicity. It improves microbial activity and symbiotic nitrogen fixation by legumes. It ameliorates the soil physical condition and improves nutrient availability of P and Mo. Lime provides an inexpensive source for

Ca^{2+} and Mg^{2+} when these nutrients are deficient at lower pH. Upon absorption by plants, it improves palatability of forages.

Philip and Martin, (2003) noted that lime supplies Mg^{2+} and Ca^{2+}, which are essential plants nutrients. Magnesium is central to chlorophyll formation and aids in the uptake of phosphorus while calcium is essentially required for various structural roles in the cell wall and membranes. Ca^{2+} is also a counter-cation for inorganic and organic anions in the vacuole. The cytosolic Ca^{2+} concentration ($[Ca^{2+}]_{cyt}$) is an obligate intracellular messenger coordinating responses to numerous developmental signals and environmental challenges (Philip and Martin, 2003).

2.5.3 Liming chemistry

Lime reacts very slowly with soil. When lime such as dolomite ($CaMg(CO_3)_2$) is applied in the soil it breaks into its cations (Ca^{2+}) and (Mg^{2+}) and carbonate ions (CO_3^-) (Smith et al., 1994). A summary of the process is described (Fig. 2) as follow;

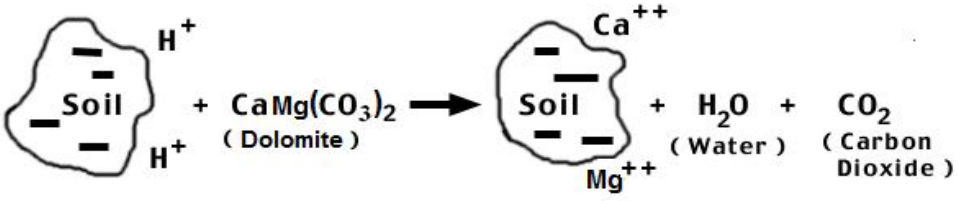


Figure 2: Lime reaction with hydrogen ions in the soil

However, the reaction is usually more complex and takes months before all lime reacts completely depending on the amount applied (Mitchell, 1999). Dolomite dissociates into ions then reacts with H^+ as shown in the following equations.

i) $CaMg(CO_3)_2 \rightleftharpoons Ca^{2+} + Mg^{2+} + 2CO_3^{2-}$

Depending on pH, the reaction may shift as follows:

ii) $CO_3^{2-} + H_2O \rightleftharpoons HCO_3 + OH^-$

iii) $HCO_3 + H_2O \rightleftharpoons H_2CO_3 + OH^-$

The production of OH^- raises the pH

2.5.4 Dolomite solubility

It is difficult to synthesize dolomite at low temperatures in the laboratory. The solubility constant (k) is measured through the ion concentration that forms upon dissolution but is not easy to reprecipitate to verify with other minerals. Lindsay (2001) put the value of k to be 18.46 using the equation below;

$CaMg(CO_3)_2 + 4\ H^+ = Ca^{2+} + Mg^{2+} + 2\ CO_2(g) + 2\ H_2O$ (Log k = 18.46)

2.5.5 Dangers of overliming

According to Harter (2007), in most tropical soils the target pH should probably not exceed about 6.0, with optimum being in the range of 5.0 to 5.5. Continued increase in pH, however, can cause molybdenum to become toxic. In addition, plants can become deficient in nutrients such as copper, zinc, boron, and manganese. This is both a result of these nutrients being less soluble at higher pH levels and decreased acid weathering of the few nutrient containing minerals still in the soil.

Harter (2007), noted that overliming in tropical soils can cause physical problem. High infiltration rates and consequent rapid leaching of bases from many tropical soils is due to their highly stable structure resulting from the tendency of iron and aluminum oxides to bind soil particles together into aggregates. Overliming can

cause a destabilization of this structure, which in turn causes soil aggregates to break apart resulting in reduced permeability and lack of adequate drainage. With the addition of dolomite to a soil, the number of small aggregates increases at the expense of larger ones. Presumably this is a case of sesquioxide (Fe and Al) stabilized aggregates being broken up by Ca^{2+} and Mg^{2+}. (Harter, 2007).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Experimental site

3.1.1 General information

The experimental site was in Kavutiri area, Gaturi North location, Embu County (Fig. 3). The experiment was carried out in a farm belonging to a farmer. The experiment was conducted from February 2010 to December 2010. The experimental site was about 20 km north of the Kenya Agricultural Research Institute, Embu. The site coordinates are 0° 24' S, 37^{o} 29' E, and slope is 6.53%. Altitude is 1700 masl. During the experiment, the average rainfall was 1730 mm. The long rains came in March to April and short rains came in October to December. The mean monthly maximum and minimum temperature were 24.0 ℃ and 13.0℃, respectively.

3.1.2 Cropping history of the experimental site

The farmer, who was the owner of the farm used for experiment, had practiced coffee cultivation, but cut down the coffee to allow maize and bean farming. According to the farmer, the fertilizers that had been commonly used in the site during the farming period included NPK, CAN and DAP. The fungicides used were Cobox® and Mealraz® while insecticides included Dimethoite® and Dusbarn®. Round up® had also been applied to eliminate weeds during coffee farming. By the time of the experiment, the site had been fallow for two seasons.

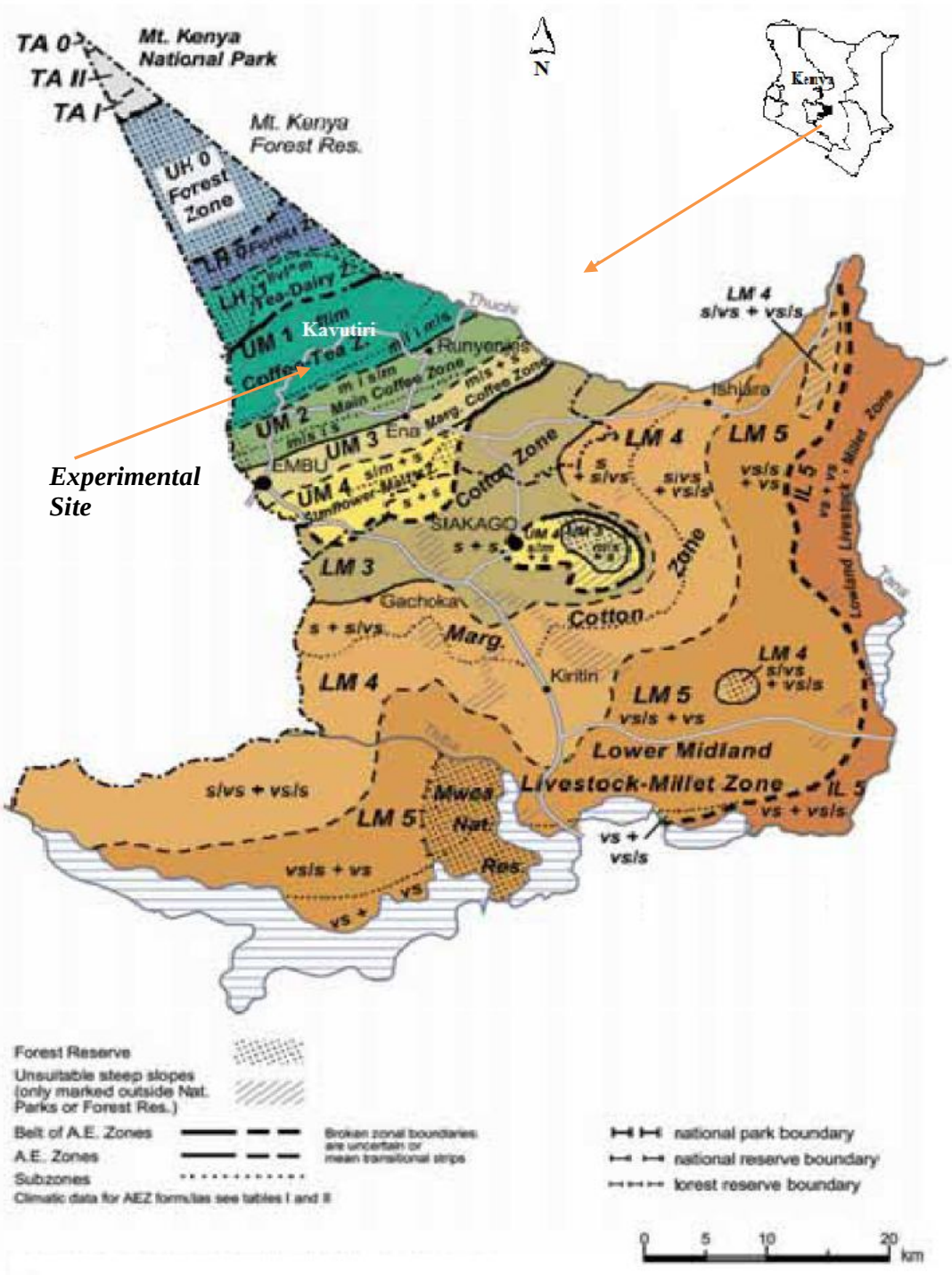


Figure 3: The Agro Ecological Zones of Embu county (Jaetzold et al., 2006), and location of the experimental site.

3.1.3 Experimental design and layout

Vegetation and debris on a land measuring 32 m x 28 m were cleared. Vegetation immediately surrounding the site was left intact. A randomized complete block design with four blocks and four plots per block was laid out using a tape measure (Fig.4). The blocking was done along the slope. The land was tilled using hoes to approximately 20 cm depth and raked to remove debris and uniformize the soil surface. The plots were laid out as shown in Fig. 4. The plot dimension was 4 m x 4 m. The distance between plots within a block was 2 m and distance between blocks was 3 m. There was an allowance of 2 m for the paths. Each plot was clearly demarcated using wooden pegs and uniformly ploughed.

3.2 Treatments

The treatments were applied on February, two weeks before the rain season began. Each block had four treatments. The treatments comprised rates of lime which were broadcasted and well mixed to 15cm depth on the plots as follows; 0 (L0), 2.4t/ha (L1), 6t/ha (L2), 8t/ha (L3). These rates were selected from earlier studies for Kavutiri soils (Mugai et al., 2008) and modified basing on liming calibration curve, to include 6t/ha which had given the best maize and bean crop yield in the area.

The lime was applied and mixed into 0-15 cm of soil depth, since this is where most plant roots and soil microbial activities were expected to occur (Graeme, 2007). Lime was mixed thoroughly with the soil to allow as much contact as possible. Plate 2 shows plots after lime had been mixed with the soil. Since lime react very slowly (Smith et al., 1994), five months reaction period was allowed. The plots were weeded

in the 5th and 11th week after treatments to simulate farmers practice. Plots were subsequently reserved for four months for colonization of flora and fauna.

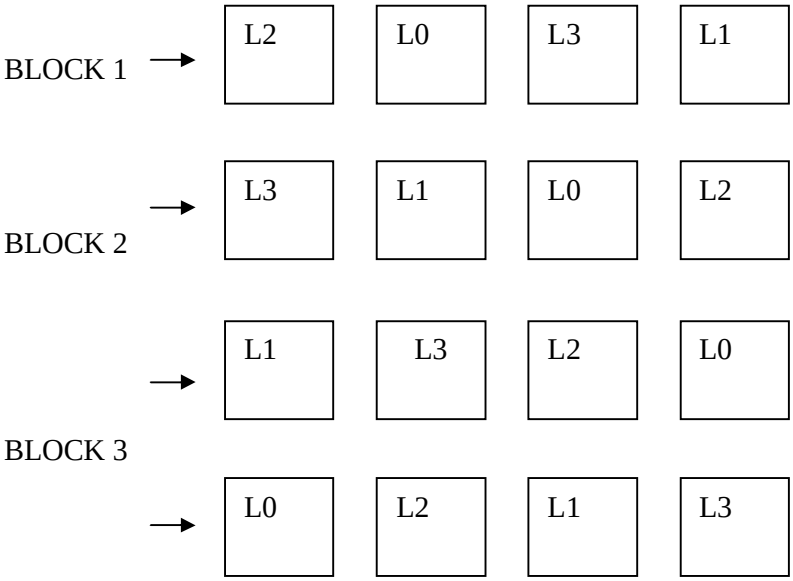


Figure 4: Layout of the blocks and plots

Plate 2: Site appearance after mixing the lime with the soil

3.3 Data collection

3.3.1 Liming material collection and characterization

Kenyan liming material was purchased from retailers packaged in bags of 50 kilograms. The trade name was Dolmax® and originated from Athi river area in Kenya. A sample of lime from the bag was obtained by scooping using a trowel and was taken to JKUAT agricultural laboratory, where it was characterized for physical and chemical properties, including particle size (successive sieving), Ca, Mg and neutralizing equivalence using method of Jackson, (1958).

The particle size was determined by passing the lime through a 50 and 100 mesh screens (0.297 and 0.149 mm, respectively). Neutralizing equivalence was determined using 1.0 g of dried lime material reacted with an excess of 1N hydrochloric acid and the excess acid titrated back with standard 1N sodium hydroxide.

Percentage calcium carbonate equivalence = (Net milliliters of 1N hydrochloric acid x5)/1 g of dried lime.

3.3.2 Soil sampling

Soil samples were collected before treatment and 9 months after treatment. Sample container was labeled prior to going to the field. Surface litter was removed from the auger sites. Graduated soil auger was used to collect seven soil sub-samples using a zigzag method per plot (Fig. 5). The augering depth was 15cm. Plate 3 shows a soil auger being driven into the soil to obtain a sub sample.

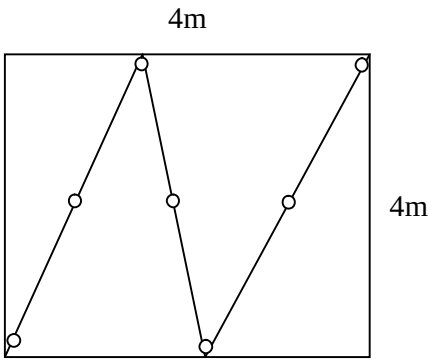


Figure 5: The zigzag lines and circles of seven sub samples collected in the plot.

Plate 3: Soil augering at the experimental site before treatment

In total, there were 16 composite samples from the experimental site resulting from the 16 plots. Auger content was put in clean plastic bucket, so that all augerings were thoroughly mixed to form a composite sample, from which 1000 cm^3 sub sample was obtained and the rest discarded. The composite sample for every plot was obtained from the sub-samples and preserved in sampling bags for laboratory analysis. This

procedure was repeated for all plots in the experiment. All sample containers with moist soils (field fresh soil) were preserved in cool boxes to prevent dehydration and transported to agricultural laboratory in JKUAT for analysis. Upon return from the field, the samples were examined for any contamination such as dust or mud, a brief rinse with water was done where necessary.

Undisturbed cores from the field were also obtained for determination of bulk density. Coring cylinders of known volume and mass were firmly driven into the cleared surface causing minimum disturbance and compaction to the core. The surrounding soil was then cut away to enable the lifting of the cylinder. The core was then lifted carefully and the end flush was trimmed with the cylinder end and then capped tightly. Samples for bulk density were collected before disturbing the ground to give an idea of the bulk density of the site.

3.3.3 Soil characterization

Field samples were taken to the agricultural laboratory (ALB) in JKUAT for evaluation. pH was determined using pH meter (EYELA model pH M2000) in water 1:2.5 and 0.01 M $CaCl_2$ 1:2.5 suspensions (Okalebo et al., 1993) determined soil pH. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) were determined after extraction by ammonium acetate buffered at pH 7.0 (Thomas, 1982). K^+ and Na^+ concentrations in soil extracts were read on 410-flame photometer while Ca^{2+} and Mg^{2+} concentrations in soil extracts were read using atomic absorption spectrophotometer (AAS) Perkin-Elmer Model 403. Available phosphorus in the soil was determined using Bray P1 method (Gary and John, 2009). The total sum of exchangeable bases ($Ca^{2+}+Mg^{2+}+K^+ +Na^+$) and exchangeable acidity (Al^{3+}) gave the effective cation

exchangeable capacity (ECEC) (Okalebo et al., 1993). Percentage base saturation was calculated by dividing the sum of exchangeable bases with the sum of cations including aluminum. Mn, was extracted with 0.1M HCl (Okalebo et al., 1993) and its concentration in soil extracts was read on AAS (Perkin-Elmer Model 403).

3.3.4 Soil root mass

Eight weeks after liming, the experimental plot surface measuring 35cm by 35 cm was randomly selected and cleared to a depth of 5 cm to remove all surface debris. Holes measuring 30 cm length x 30 cm width x 50 cm depth were dug vertically in the plots. Using a tape measure, a ruler and a graduated trowel, four cubes of 10 cm x 10 cm x 10 cm were cut along the soil profile as follows; 6-15 cm, 16-25, 26-35 and 36-45cm. The resulting volumes of soil from each depth and from all plots were stored in separate sampling bags for laboratory work.

In the laboratory, a sub sample of 300 grams was obtained from each volume of the soil collected and soaked in a beaker of water before shaking to release roots from the soil solution. It was then sieved using 0.25 mm sieve and rinsed with pressurized water to wash all soil out. Roots were then physically separated from other material and air dried for 48 hrs before weighing and recording.

3.3.5 Sampling for biodiversity

Biodiversity in this study was grouped into flora diversity and fauna diversity. Fauna was grouped into above and below ground fauna. Below ground fauna was further grouped into soil macro fauna, soil meso fauna and soil micro fauna. These groupings were made for ease of recording. The initial sampling was done after

demarcating the experimental site to give an insight of flora and fauna on the site. Since lime react very slowly (Smith et al., 1994), five months reaction period was allowed. Subsequent sampling of flora and fauna that colonized the site took place six and nine months after the treatments. The sampling of the fauna and flora was done in the same days: 7.30 am to 10.30 am was allocated to fauna while the rest of the day was used to enumerate the flora species.

3.3.6 Flora sampling

Recording of the flora species was done insitu. Where information for identification was not available, flora leaves or fruiting structure or both were cut and preserved by pressing in between newspapers for identification through referenced herbarium.

A quadrant of 1m x 1m was used to guide the sampling. Sixteen quadrants were taken per plot starting from the right bottom side of the plot and continuing to the rest of the plot to ensure nothing was left out or repeated (Fig. 6). Within each quadrant, different species of flora were directly counted and recorded. Enumeration of the flora was done per block per day; hence four consecutive days were used to complete the flora recording.

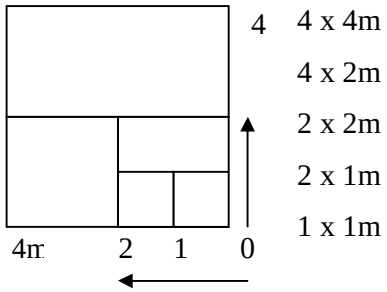


Figure 6: Sampling design within the treatment plots.

3.3.7 Fauna sampling

Fauna formed the bulk of the data collected hence grouped into two parts namely, above ground and below ground fauna. The above ground fauna data was collected in the morning hours from 7.30 am to 10.30 am. During the collection of data before liming, the temperature was 25.4^0c and calm. During the sixth month data collection, the temperature was 24.3^0c and calm while at the ninth data collection, the temperature was 24.7^0c and calm. Flying organisms relevant to 4 m x 4 m plots were sampled using sweep nets (Plate 4). Recording of fauna was done insitu. Where information for identification was not adequate, fauna were preserved with Ethyl acetate in flasks (Plate 5) and stored in cool boxes. Once the organisms were completely knocked by the ethyl acetate, they were pinned on the insect box (Plate 6) for further reference.

Plate 4: Trapping flying fauna for identification

Plate 5: Beetles preserved in the flasks using cotton wool wet with ethyl acetate

Plate 6: Organisms pinned onto the insect box

Due to size of the experimental plots (4 m x 4 m), arthropods formed the largest share of the above ground fauna data. Non-flying fauna data was collected by counting fauna in a quadrant of 1 m x 1 m, that was laid as shown in Fig. (6). Different species and their frequencies were counted and recorded. Flying fauna were sampled using a sweep net. The net was swept through the plot sixteen times to cover at least ever m^2 in a 4 m by 4 m plot and organisms counted and tabulated.

Below ground fauna soil samples were collected as indicated in section 3.3.3. The data collected included that of micro, meso and macro fauna. Earlier, micro-fauna composed of bacteria, fungi and actinomycetes, but actinomycetes have so far been grouped as bacteria (Karnataka, 2007). Micro-fauna were cultured as described by Okalebo et al., (1993). Fresh soil samples from the site were placed on a clean bench from which inoculums were extracted by weighing 1g of the soil (Plate 7) from each sample. The inoculums were serially diluted by adding 1 x of suspension to 5 x of diluents (10^{-5}). 1gram of the soil was obtained by weighing and put in the in the first test tube, 1ml suspension from first tube was added to the second tube, and the 1ml of the second to the third and this continued to the fifth tube. Each tube had 9ml of sterile distilled water. Three plates were used for each sample for statistical reasons (Miles et al., 1938). Nutrient agar (NA) and Potato Dextrose Agar (PDA) were used as media for bacteria and fungi, respectively. The media was added into plates and sterilized. Plates were divided into 4 equal sectors and labeled. The surfaces of the plates were made sufficiently dry to allow a 20 µl drop to be absorbed in 15 - 20 minutes. In each sector, 20 µl of the 10^{-5} dilution was dropped onto the surface of the NA or PDA and the drop was allowed to spread naturally. The plates were left

upright on the bench for 30 minutes (Plate 8) to dry before inversion and incubation at 37°C for 48 hours for bacteria and 4 days for fungi.

Plate 7: Apparatus used for weighing soil samples and serial dilutions

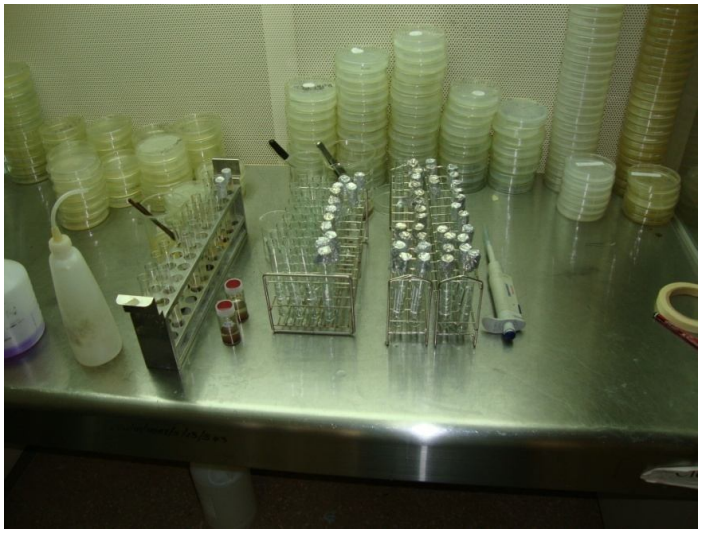


Plate 8: Inoculated plates placed upright on the clean bench.
Plates were transferred to the growth chamber after 30 minutes.

Bacteria and fungi and were quantified using colony forming units (cfu). Colonies were counted (Plate 9) in the sector where the highest number of full-size discrete colonies could be seen. The sectors counted contained between 2-20 colonies.

Plate 9: Counting the colony forming units

Meso-fauna in the experiment composed of nematodes. A 100cm^3 of fresh soil composite sample from each plot obtained as shown on (Fig. 5), was measured in the laboratory for nematode extraction, using a sieving and centrifugation procedure (Okalebo et al., 1993). Nematodes were counted under a dissecting microscope, and the data recorded.

Nuria et al., (2008), indicated that soil macro fauna consist mainly of earthworms, beetles, ants, termites, millipedes, snails and slugs. A 100 cm^3 composite sample from each plot was obtained as shown in Fig. 5 for determination of macro fauna. These included earthworms, beetles, ants, termites, millipedes, snails and slugs. They

were counted directly in the field using naked eye for earthworms, beetles, termites, millipedes, snails and slugs and magnifying glass for small ants.

3.4 Data analysis

3.4.1 Soil properties analysis

Soil properties data collected in the plots at the site before liming were compared with means of L0 plots nine months after liming using t-test. This gave an indication of the influence of time during the experiment. The variance of the data obtained after liming was analysed (ANOVA) using GenStat software at $\alpha = 0.05$ and means were separated using Duncan's Multiple Range Test at $p = 0.05$.

3.4.2 Biodiversity analysis

Five measurements were used to express biodiversity. They included species Frequency, abundance, richness (S), evenness (J) and Shannon's diversity index (H'). Population is a group of organisms of the same species inhabiting a given area. It was obtained by counting organisms with respect to their species in a plot. Abundance is the quantity of species in a given unit area (Beals et al., 1998). It was obtained by counting all species in a plot. Richness indicated the number of different species in a given area (Butler and Chazdon, 1998). It was obtained by counting different types of species in a plot.

Species evenness defined the proximity of numbers of individual species in an area (Emerson and Brent, 2005). Usually, evenness is constrained between 0 and 1. When all species are found in all plots as equally as possible, there is less variation in communities and the evenness is very close to 1 (high) and when one or very few

species dominate the others the evenness value is close to 0 (low) (Beals et al., 1998). The formula for evenness is as follows:

$$E = \frac{(1 - SI)}{(1 - SI_{max})}$$

Where E is evenness, S is number of species and I is a diversity index.

However, evenness by itself has a disadvantage because it only measures equitability but lose the information on species richness. As a result, in this experiment a biodiversity measurement that combined species richness and evenness was included. This was Shannon's diversity index. Shannon's diversity index (H') indicates the number of different species in an area as weighted by abundance in the same area (Beals et al., 1998). The index is given by the formula:

$$H' = -\sum pi \ln pi$$

Where (∑) is the summation, (pi) is proportion of each species to the whole species in the treatment plot and (ln) is the natural log.

This index meant that for each type of species (i), the proportion (p) to the whole species in plot was determined, and then multiplied by the natural log (ln) of itself (p ln p). All the resulting numbers were added up (∑) and multiplied with (-) to turn them into a positive number for convenience as explained by Beals et al., (1998).

The means of the species population in plots before liming were compared with means of L0 (plot with no lime) nine months after liming using studentized t-test.

This gave indication on whether time had any significant influence on organisms during the experiment. After the treatment, species frequencies in the plots were again described along the levels of liming.

The diversity parameters (species abundance, richness, evenness and Shannon's diversity index) were obtained through Ms excel program using Hutcheson (1970) methodology that simplified the computations. The method allows input of frequencies of two different categories (level 1 and level 2) and computes species abundance, richness, evenness and Shannon's diversity index. In this experiment, frequencies from the treated plots (L1, L2 and L3) were individually put in level 1 category while the control (L0) was put in level 2 category. As explained in Zar, (1996), this method also estimated the variance of the diversity hence allowing the treated plots to be statistically compared with the control at $\alpha = 0.05$. Means were separated using Duncan's Multiple Range Test at $p = 0.05$.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characterization of lime

The lime used was cream white in color, granular in structure, and effervescenced weakly with cold hydrochloric acid. Table 5 shows the analytical results of the limestone used in the experiment. The contents of the components of lime may vary from one location to another, the result provided here are for the lime used in the experiment. This limestone had an advantage over other forms such as calcite ($CaCO_3$) because it could provide both Ca and Mg hence, enriching the soil better. Liming material is classified according to its Ca and Mg proportions (Brett et al., 2005). As indicated in Table 5, the liming material contained CaO and MgO but they were in unequal proportions (47.4% and 18.5%, respectively) hence, according to Brett et al. (2005), it could be classified as dolomitic limestone.

Table 5: Analytical results for the limestone from Athi river, Kenya.

Component	value (%)
1) Total nutrient content	
a) CaO	47.4
b) MgO	18.5
c) Ca	22.2
d) Mg	8.7
2) Lime passing through	
a) 100 mesh	32
b) 50 mesh	46
3) $CaCO_3$ neutralizing equivalence	74.5

The neutralizing equivalence of 74.5% indicated that the liming material had impurities (Douglas and Lingenfelter, 1995). Mainly such impurities include plants nutrients such as Na and K among others (Brett et al., 2005).

4.2 Soil physical and chemical properties

The soil structure was found to be polyhedric blocky with shiny ped surfaces. This characteristic is common for nitisols (Sombroek et al., 1984). The texture (USDA, 1975) was clay (Sand 26%; Silt 26%; Clay 54%) but had loamy physical characteristics. This was probably due to its expected high content of kaolinitic and hydrous oxides (Mugai, 2008). Before liming, bulk density was 0.77g/cm^3. According to USDA (2008), clayey soils should have bulk density less than 1.1g/cm^3 for proper root growth, hence these soils had appropriate bulk density. Table 6 shows comparison of the means of the soil properties before liming and the L0 (control) nine months after liming. This specified the influence of time on the soil properties in the site during the experiment. In all cases, p-value was higher than 0.05, indicating that there were insignificant variations within the soil properties between the unlimed plots (L0) and the initial soil properties before liming.

Table 6: Soil chemical and physical properties before liming and L0 nine months after liming

	Soil sampling depth 0-15 cm, n = 4				
Soil properties	**Before liming**	**L0 after 9 months liming**	**t-statistics**	**p-value**	**SD**
pH water 1:2.5 suspension	4.23	4.15	1.34	0.23	0.079
BS%	24.0	23.7	0.67	0.53	0.634
Available P (mg/kg)	17.53	16.88	0.88	0.41	1.040
Exchangeable Mn (mg/kg)	112.68	113.50	0.48	0.65	2.460
Bd (g/cm^3)	0.77	0.77	1.00	0.36	0.007
Exchangeable cations (cmole ($^+$)/kg)					
Exchangeable Al	5.25	5.26	0.60	0.57	0.018
K	0.18	0.18	0.28	0.79	0.013
Ca	0.84	0.84	0.93	0.39	0.008
Mg	0.51	0.50	1.41	0.21	0.005
Na	0.06	0.05	1.10	0.32	0.001
CEC_{ac}	1.64	1.63	1.09	0.32	0.016
ECEC	6.83	6.88	1.41	0.21	0.050

SD - standard deviation, ac – extracted by ammonium acetate, level of confidence = 95%

This implied that it was appropriate to use the unlimed plots to compare the treated plots after nine months of the experiment.

Table 7 shows the effect of lime on soil properties after nine months, with treatment means separated using DMRT. Liming increased the pH, Ca, Mg and phosphate levels in the soil. The pH from L0 to L3 determined in water, increased from 4.2 to 5.9 (40.5%) while in $CaCl_2$ suspensions, it increased from 3.8 to 5.3 (39.5%). Increase in pH after liming was expected due to high presence of CO_3^{2-} in dolomite.

Other soil parameters that increased with increase in liming from L0 to L3 were BS%, available phosphorus and exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+). The increase in base saturation was due to the supply of exchangeable cations by the lime

(Mitchell, 1999). The increase in Ca^{2+} and Mg^{2+} from L0 to L3 was expected, because the two were the main constituents of dolomite and were deposited during soil liming. K^{+} and Na^{+} increase may have been the result of impurities in the dolomite (Brett et al., 2005). The increase in available P from 18.0 to 45.5 for L0 and L3, respectively was attributed to mobilization of fixed P as pH increased (Tagwira et al., 1992).

The direct outcome of lime application was the increased Ca^{2+} and Mg^{2+} saturation percentage on the exchange sites of the soil colloid and the elevated soil pH in soil solution due to carbonate reactions (Douglas and Lingenfelter, 1995). The beneficial effect of liming on soil physical properties resulted from the elevated ionic strength in the soil solution and the domination of Ca^{2+} and Mg^{2+} on the exchange sites at the expense of H^{+} (Aura, 2005). While liming to pH 6.5 may form calcium triphosphate once again immobilizing phosphorus (Tagwira et al., 1992), the highest liming rate in the experiment, which was 8t/ha (L3) did not raise pH beyond 6.0. This was probably due to high aluminum ions in Kavutiri soils. Aluminum ions are known to buffer soil from pH changes (Douglas and Lingenfelter, 1995).

Table 7: Soil chemical and physical properties in different lime rates nine months after liming

Liming rates	Soil sampling depth (0-15 cm)												
	pH water	pH(0.01M $CaCl_2$)	BS	Available P	Extractable Mn	Bd	Exchangeable Al	K	Ca	Mg	Na	CEC_{ac}	ECEC
	1:2.5 suspension		%	mg/kg		g/cm^3	cmole $^{(+)}$/kg						
L0	4.2a	3.8a	23.6a	18.0a	111.0d	0.77a	5.28d	0.18a	0.84a	0.50a	0.055a	1.63a	6.9c
L1	4.7b	4.2b	25.4b	24.2b	82.8c	0.75a	5.03c	0.20ab	0.90b	0.55b	0.062b	1.70a	6.7b
L2	5.6c	5.0c	34.3c	34.0c	58.9b	0.71a	4.08b	0.21bc	1.11c	0.74c	0.068c	2.19b	6.2a
L3	5.9d	5.3d	37.5d	45.5d	44.1a	0.67b	4.01a	0.23c	1.20d	0.78d	0.084d	2.36c	6.3a
Means	5.10	4.58	30.20	30.43	74.20	0.73	4.60	0.21	1.01	0.64	0.07	1.97	6.53
Significance	**	**	*	**	*	*	*	*	**	**	*	*	*
CV (%)	1.04	1.38	3.63	3.30	0.66	4.57	5.41	3.65	0.87	3.55	2.15	2.78	1.03

L0 = 0t/ha, L1 = 2.4t/ha, L2 =6t/ha and L3 = 8t/ha. ac – extracted by ammonium acetate. Means in the same row that are followed by the same letter do not differ significantly, p = 0.05, grouped using Duncan's Multiple Range Test. *, ** - significant at 5% and 1%, respectively. n = 4.

Factors that decreased with increase in liming were, bulk density (Bd), ECEC, exchangeable Al and Mn. They decreased from L0 to L3. Liming lowered Bd from 0.76 (L0) to 0.67 (L3). (Refer to 4.6.2.3). Since ECEC is a set of CEC and the acidity (Al^{3+}), its decrease was attributed to decrease in exchangeable Al, which was caused by liming. Exchangeable Al and Mn probably decreased due to increase in pH that resulted from liming. When the soil pH increased, the exchangeable Al and Mn in the soil may have formed into hydroxides (Mitchell, 1999).

Figs. 7 and 8 show liming lowered exchangeable Al^{3+} and Mn in the soil and raised the soil Ca, Mg and phosphate levels. Al and Mn reduced in the soil following logarithmic regression, $R^2 = 0.867$ and $R^2 = 0.992$, respectively. On the other hand, Ca and Mg increased exponentially, $R^2 = 0.956$ and $R^2 = 0.927$, respectively, while phosphate had a polynomial increase in the soil $R^2 = 0.999$.

The exponential increment in Ca and Mg upon liming confirms that lime indeed supplied Ca and Mg into the soil (Douglas and Lingenfelter, 1995). The logarithmic decrement in exchangeable Mn^{2+} and exchangeable Al^{3+} with increase in liming could be due to the decreased solubility of their oxides (Mitchell, 1999).

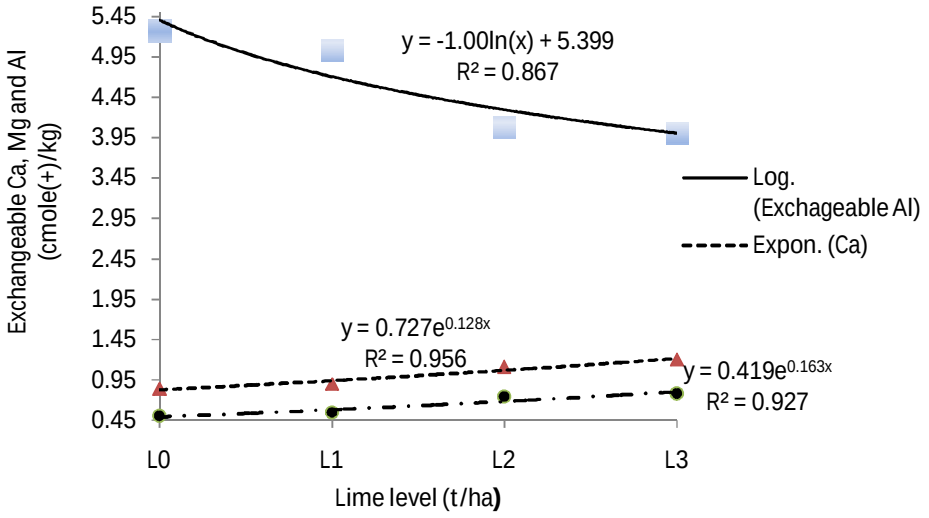


Figure 7: The relationship between exchangeable Al, Ca and Mg along different lime levels in Kavutiri soils nine months after liming.
L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. n = 4. Liming decreased exchangeable Al logarithmically while increasing Ca and Mg exponentially along different liming levels in Kavutiri soils in nine months after liming.

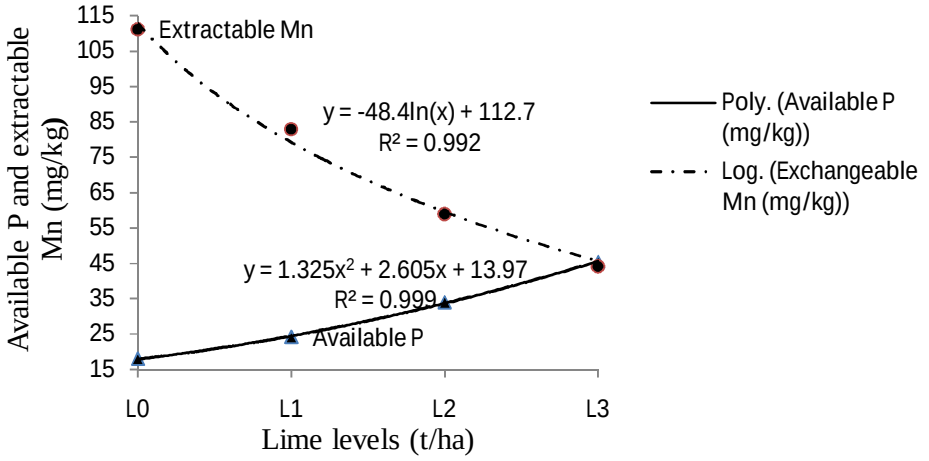
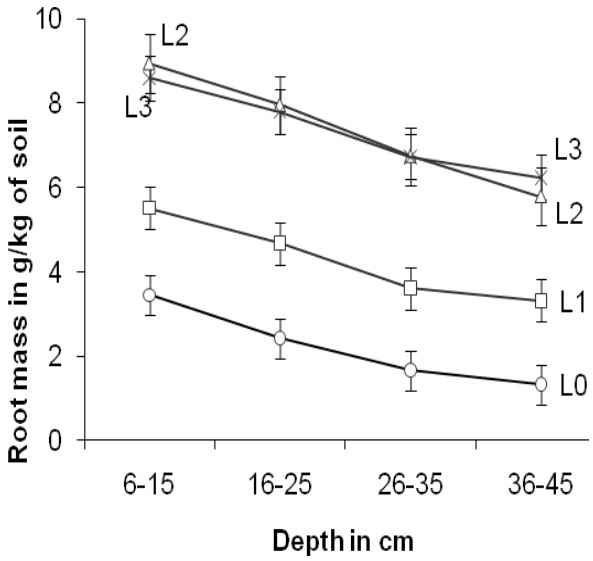


Figure 8: The relationship between exchangeable Mn and available P along different lime levels in Kavutiri soils nine months after liming.
L0 = 0t/ha, L1 = 2.4t/ha, L2 =6t/ha and L3 = 8t/ha. n = 4. Liming decreased exchangeable Mn logarithmically and increased available P through a polynomial trend along different liming levels in Kavutiri soils in nine months after liming.

4.3 Soil root mass

Fig. 9 shows root mass along the profile eight weeks after liming. The root extracted indicated that the root mass was highest in the first 15cm of the soil depth as expected (Graeme, 2007). L3 and L2 had the highest root mass on all depths. L0 had the lowest root mass on all depths. L3 and L2 had most roots that had developed appropriately probably because liming had reduced the toxic Al^{3+} levels that cause root tip destruction (Yamamoto et al., 2006). Root mass on treated plots continued to be higher along the profile as compared to the control due to downwards movement of the liming material (Abigael et al., 2006). With this respect, L3 had highest root mass along the profile, probably indicating it had more lime that had moved downwards. As Fig. 9 shows root mass along the profile eight weeks after liming. indicaRoots from L2 and L3 were many and large while L0 had small roots that seemed stunted. This was probably due to high Al that attacked tips of sensitive plants and limited elongation. Yamamoto et al. (2006), found similar scenario in wheat cultivars.



Total root mass

L0 = 8.88g/kg of soil

L1 = 17.12g/kg of soil

L2 = 29.43g/kg of soil

L3 = 29.35g/kg of soil

Figure 9: Soil root mass along the soil profile and the overall root mass per treatment in Kavutiri soils eight weeks after liming.
L0 = 0t/ha, L1 = 2.4t/ha, L2 =6t/ha and L3 = 8t/ha, bars following each lime level along the depth indicate the standard error deviation.

4.4 The frequencies of flora species

Table 8 shows the influence of time on the frequencies of flora species before liming and the control plots nine months after liming ($\alpha = 0.05$). The t-test probability values for all the flora species were higher than 0.05 indicating that the differences between their means were insignificant. There was no enough evidence to conclude that nine months had influenced the flora diversity in the untreated plots at $\alpha = 0.05$. These results implied that L0 (control) could be used to compare the effects of the treatments nine months after liming.

Table 8: The means of the flora species frequencies before liming and L0 nine months after liming

Name	Before treatment	L0 nine months after liming	T-test p-value	SD
Ageratina adenophora	39	40	0.28	1.20
Ageratum conyzoides	4	3	0.13	0.93
Agropyron repens	2.75	3	0.82	1.36
Bidens pilosa	2	1	0.13	0.93
Commelina benghalensis	1.25	1	0.62	0.64
Cortoderia spp.	1.75	2	0.71	0.83
Cyperus esculentus	7	8	0.13	0.93
Luceana spp.	2	1	0.13	0.93
Oxalis latifolia	15	17	0.07	1.31
Penisetum spp.	22.25	22	0.82	1.36
Pteridium aquilinum	62	63	0.47	1.77
Sonchus arvensis	3	2	0.13	0.93
Spergula arvensis	1	1.25	0.75	0.99
Tagetes minuta	2	1.25	0.18	0.74
Viola sp	0.25	0	0.39	0.35
Mwaura ciau (Emb.)	0.25	0	0.39	0.35

Emb. - Embu local language, SD - standard deviation, Level of confidence = 95%, n = 4. L0 = nil lime level.

Table 9 shows the frequency of flora species means in sixth and ninth months after liming with means separated using DMRT along the four treatments at α 0.05. In the sixth month, the treatments differed significantly from the control (L0) indicating that lime had influenced the flora species frequencies at α 0.05. Flora frequencies within the treatment plots differed with particular species. This was probably because different plants had different survival mechanisms and hence responded to ecological changes differently (Emerson and Brent, 2005). Means of nine plants did not differ from each other along the treatments levels. These were *Spergula arvensis L.*, *Stellaria media*, *Tagetes minuta L. Viola sp. L.* Muvururo (Emb.), Muvuria ndudi (Emb.), Mwaura ciau (Emb.), *Setaria pumila* and *Ageratum conyzoides L.*

The most remarkable difference between nine and six months' frequencies data was that all plants in the ninth month show significant difference from each other while in the sixth month, nine plants did not differ significantly. In the ninth month, *Ageratum conyzoides* and *Sonchus arvensis* increased with increase in liming from L0 to L3 probably due to improved nutrition (Mitchell, 1999). *Echium sp, Medicago sativa,* Mwaura ciau, *Oxygonium sinuatum* and *Viola sp* were absent in L0 but colonized L1 and increased with increase in liming indicating that liming may have eliminated the factors that were suppressing their growth (Susan and Fahrig, 1995). *Fallopia convolvulus,* Muvururo, Muvuria ndudi, *Stellaria media* and *Polygonum aviculare* were absent in L0 and L1 but colonized L2 and L3 probably indicating that the factor that was suppressing their growth needed higher liming level than L1 and hence it took liming level L2 to trigger their emergence (Susan and Fahrig, 1995).

Setaria pumila colonized plots from L2 only to decrease at L3 probably showing that this species needed a narrow range of liming level conditions to thrive below or above which it could not grow well (Butler and Chazdon, 1998). It may have attained that level at L2. *Agropyron repens, Bidens pilosa, Cyperus esculentus* and *Spergula arvensis* attained a maximum abundance at L1 and showed no further increase with *Spergula arvensis* registering significant decline at L3 from L1. *Commelina benghalensis, Cortoderia spp., Luceana spp.* and *Tagetes minuta* attained a maximum value at L2 only for *Luceana spp.* to decline at L3. Similar phenomenon was also observed by Mugai et al., (2008) where bean yield started declining after liming to pH 5.8.

Table 9: The means of flora species frequency in different liming rates six and nine months after liming

	Treatments (liming rates) means (*counts*) n = 4							
	Sixth month				Ninth month			
	L0	L1	L2	L3	L0	L1	L2	L3
Ageratina adenophora L.	37c	32b	26a	26a	39c	33b	25a	24a
Ageratum conyzoides L	5a	5a	6a	6a	3a	6a	15b	22c
Agropyron repens	4a	7b	6ab	6ab	3a	10b	8b	7b
Bidens pilosa L.	2a	5b	6b	3ab	1a	4b	6b	5b
Commelina benghalensis L	1a	1a	17b	17b	1a	2a	20b	19b
Cortoderia spp. L.	3a	6b	13c	14c	2a	12b	16c	15c
Cyperus esculentus L.	9a	11a	12ab	12ab	8a	15b	13b	14b
Echium sp. L	1a	3b	4b	3b	0a	4b	6c	10d
Fallopia convolvulus L	0a	1a	3b	2b	0a	0a	6b	4b
Luceana spp. L	0a	1a	4b	4b	1a	2ab	7c	4b
Medicago sativa L.	0a	3b	3b	3b	0a	2a	5b	8c
Oxalis latifolia L.	12ab	14a	12ab	8a	17b	15b	8a	5a
Oxygonium sinuatum Meish.	1a	3a	7b	4ab	0a	8b	11b	8b
Penisetum spp. L.	19b	20b	15a	15a	22b	22b	12a	11a
Polygonum aviculare	0a	0a	6b	6b	0a	0a	4b	7c
Pteridium aquilinum L.	54c	52c	43b	39a	59c	51b	36a	35a
Setaria pumila	1a	0a	2a	3a	0a	0a	8c	6b
Sonchus arvensis L.	1a	1a	4b	6b	2a	3a	9b	13c
Spergula arvensis L.	3a	4a	3a	4a	1a	13c	10c	5b
Stellaria media	1a	1a	1a	2a	0a	0a	4b	6b
Tagetes minuta L.	4a	4a	3a	4a	1a	3ab	5b	7b
Viola sp. L	0a	1a	2a	2a	0a	2a	5b	7b
Muvururo (Emb.)	0a	1a	2a	1a	0a	0a	4b	6b
Muvuria ndudi (Emb.)	0a	0a	2a	3a	0a	0a	4b	4b
Mwaura ciau (Emb.)	0a	0a	2a	2a	0a	2a	7b	5b

Emb. - Embu local language; L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha; Means in the same row and under same time scale (sixth or ninth month) that are followed by the same letter do not differ significantly, Duncan's Multiple Range Test p = 0.05.

This was attributed to increasing insolubility of metal trace elements (Mitchell, 1999). However, in this experiment, some indigenous flora species stopped

increasing after liming to L2 such as *Commelina benghalensis, Cortoderia sp, Luceana sp* and *Tagetes minuta* while others like *Agropyron repens, Bidens pilosa, Cyperus esculentus* and *Spergula arvensis* attaining a maximum at L1, which had a pH of 4.7. Some scientists (verbal communication) have speculated that some useful microorganisms that are adapted to acidity might be decreasing upon pH rise above 5.6. This line of thinking requires more research. *Ageratina adenophora, Pteridium aquilinum, Oxalis latifolia* and *Penisetum sp* were very abundant at L0 affirming that some plants can adapt to high acidity (pH 4.2) as well as to elements such as aluminum agreeing with earlier findings (Mugai et al., 2008). However, the four; *Ageratina adenophora, Pteridium aquilinum, Oxalis latifolia, Penisetum sp* may have reduced due to liming probably because of enhanced competition from other species (Hutchinson 1959) that increased after liming.

Table 10 shows the abundance, richness and evenness of flora species nine months after liming. There was a general increase in flora abundance from 160 (L0) to 257 (L3), richness from 14 (L0) to 25 (L2 and L3) and evenness from 0.67 (L0) to 0.94 (L2 and L3). This was probably due to the ability of liming to stabilize the nutrients and pH that had become low in acidic soils (Brett et al., 2005). In this case, liming raised Mg and Ca, mobilized P and helped fixing elements such as Mn and Al hence reducing their toxicity (Gordon, 1999). Liming provided a platform for essential elements to be absorbed by plants leading to stability and high species evenness in L2 and L3. Low evenness in L0 was caused by high population of some species such as *Pteridium aquilinum* and high suppression of others such as *Sonchus arvensis.*

Table 10: The abundance, richness and evenness of flora species nine months after liming

	Treatment means (*counts*)			
	L0	**L1**	**L2**	**L3**
Abundance	160a	209b	254c	257c
species richness (S)	14a	19b	25c	25c
Evenness (J)	0.67a	0.83b	0.94c	0.94c

L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. Means in the same row that are followed by the same letter do not differ significantly, p = 0.05, separated by Duncan's Multiple Range Test, n = 25.

The trend where some species dominate others greatly, threatens an ecosystem because in the long run suppressed species may eventually become extinct (Susan and Fahrig, 1995). Liming to L2 and L3 indicated that such threats could be minimized. Dominating species reduced as liming proceeded to L3. This was advantageous because the conditions became favorable enough for more species to inhabit more niches (Slattery and Hollier, 2002), leading to more species richness as was observed in the treated plots. Ironically, some flora species such as *Bidens pilosa* and *Tagetes minuta* in L0 exhibited notable stem coloration that was absent in limed plots. This requires further studies for explanation.

4.5 Flora diversity index

Fig. 10 shows that the flora diversity index of the treated plots differed significantly from the control. L2 and L3 gave the highest diversity index score of 3.02 and 3.01, respectively. Diversity in L2 and L3 did not differ from each other in the nine months of the experiment. The higher flora diversity index in limed plots than control (L0) can be interpreted that biodiversity was responding to effect of liming of

lowering acidity and reversing the toxicity of elements such as Al and Mn as well as mobilizing fixed P (Mitchell, 1999). The higher flora diversity in limed plots resulted from increase in flora abundance, richness and evenness in limed plots (Beals et al., 1998).

4.6 Fauna diversity index

Generally, fauna diversity increased with increase in flora diversity. Fig. 10 shows above ground fauna increased with increase in liming up to L2 (6t/ha) to biodiversity index of 3.42 after which there was no further increase. This probably indicated that the above ground fauna responded to liming indirectly (Maneepitak, 2007). The flora is the primary producer to which fauna depend on (Brett et al., 2005). Hence, higher flora diversity led to higher fauna diversity. The similarity in patterns of flora and fauna diversity was attributed to close relationship between fauna and flora (Susan and Fahrig, 1995).

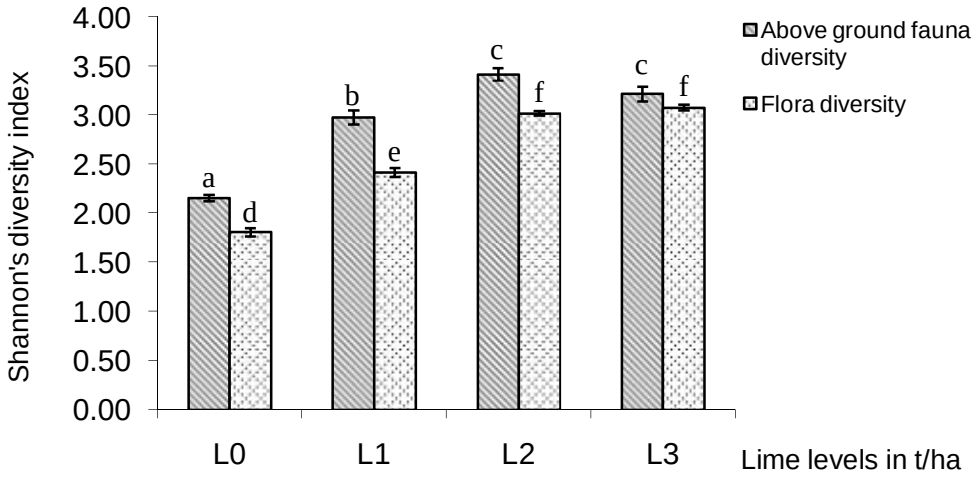


Figure 10: Flora and above ground fauna diversity nine months after liming. L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. L0 had the lowest diversity followed by L1 while L2 and L3 had the highest. Bars followed by the same letter within each diversity category do not differ significantly, p = 0.05, separated using Duncan's Multiple Range Test, n = 4.

4.6.1 The frequencies of above ground fauna

Table 11 shows the time influence on above ground fauna frequencies before liming and the L0 (control) treatment plots nine months after liming. The p value was higher than 0.05 in all cases indicating that in nine months after liming, the fauna population in L0 plots did not differ significantly from the initial one before liming. Similarly, the below ground fauna species before liming and the L0 nine months after liming did not differ significantly from each other. It was therefore appropriate to compare the effects of liming on fauna species with the L0 after nine months.

Table 11: The means of the above ground fauna species frequencies before liming and L0 nine months after liming

Name	Before liming	L0 nine months after liming	T-test p-value	SD
Banasa dimiata	5.8	5.3	0.50	0.93
Bombus ternarius	3.0	4.0	0.09	0.76
Brachiacantha ursina	1.5	1.0	0.18	0.46
Brephidium exilis	1.5	1.3	0.54	0.52
Camponotus floridanus	13.3	14.0	0.39	1.06
Chinavia hilaris	1.3	1.0	0.64	0.64
Coenosia sp.	52.3	53.8	0.24	1.60
Culiseta sp	60.3	60.8	0.61	1.20
Euschistus sp.	8.0	7.0	0.09	0.76
Gryllus pennsylvanicus	1.5	1.3	0.68	0.74
Lophocampa sp.	3.8	3.8	1.00	0.71
Lopidea sp.	2.8	3.3	0.50	0.93
Melanoplus chiricahuae	30.3	30.0	0.64	0.64
Metaparia viridimicans	2.3	3.3	0.13	0.89
Neoconocephalus triops	1.5	2.3	0.34	0.99
Papilio troilus	5.8	5.8	1.00	0.89
Reticulitermes sp	9.3	10.8	0.09	1.20
Scudderia sp	3.8	3.3	0.40	0.76
Tenodera	1.5	2.3	0.34	0.99
Tipula colei	2.8	3.3	0.56	1.07
Ummidia sp	1.3	1.8	0.40	0.76

SD - standard deviation, Level of confidence = 95%, n = 4, L0 – nil lime level

Table 12 shows the fauna frequencies in the control and the limed plots, nine months after liming, with the means separated using DMRT along the four treatments. The observed p was much lower than 0.05, hence the fauna frequencies differed significantly from the control (L0), indicating that treatments had influenced the fauna population at α 0.05. Arthropods dominated the above ground species probably due to the scale of the experiment as noted earlier by William, (1998) in his "Mass

effect" theory, that different species may be competitively superior in different microhabitats.

22 fauna species increased from L0 to L2 and did not show further significant increase or decrease to L3. They included; *Banasa dimiata, Bombus ternaries, Brachiacantha ursine, Brephidium exilis, Camponotus floridanus, Chinavia hilaris, Euschistus sp, Gryllus pennsylvanicus, Lophocampa* sp, *Lopidea* sp, *Megachiloides* sp, *Papilio troilus, Phytocoris antennalis, Pollenia* sp, *Reticulitermes* sp, *Rhizophagus remotes, Scudderia* sp, *Stethaspis* sp, *Tipula colei, Strachiini* sp and *Ummidia* sp. This was attributed to flora that may have increased in the same pattern (Brett et al., 2005). However, two, *Neoconocephalus triops* and *Tenodera* increased from L0 to L2 and decreased at L3 while *Melanoplus chiricahuae* increased considerably with increase in liming from L0 to L3. Five fauna species namely: *Helorus anomalipes, Phytocoris antennalis, Rhizophagus remotes, Stethaspis sp* and *Triepeolus lunatus* were absent in L0 but appeared in L1 and increased to L2. Two of these species decreased at L3, these were *Helorus anomalipes* and *Triepeolus lunatus.* Four others, *Ceratina* sp, *Megachiloides* sp, *Strachiini* sp and *Pollenia* sp appeared at L2 and remained the same in L3 apart from *Ceratina* sp, *which* pointed to considerable increase at L3. *Metaparia viridimicans* frequency did not differ in L0 and L1, L1 and L2 as well as in L2 and L3. *Lopidea* sp did not show clear difference between L0 and L1 but differed clearly from L0 and L1 at L2 and L3.

Table 12: The means of the above ground fauna species frequencies nine months after liming

	Treatment means (*counts*)			
Fauna name	L0	L1	L2	L3
Flying fauna				
Banasa dimiata	5a	22b	37c	39c
Bombus ternarius	4a	15b	34c	32c
Brachiacantha ursina	1a	8b	32c	31c
Brephidium exilis	1a	4b	11c	12c
Ceratina sp	0a	0a	15b	18c
Chinavia hilaris	1a	4b	10c	11c
Coenosia sp	54a	51a	46a	48a
Culiseta sp	61c	56b	48a	49a
Euschistus sp	7a	18b	39c	40c
Gryllus pennsylvanicus	1a	6b	15c	14c
Helorus anomalipes	0a	5b	15d	10c
Megachiloides sp	0a	0a	12b	11b
Melanoplus chiricahuae	30a	33b	38c	52d
Neoconocephalus triops	2a	6b	18d	10c
Papilio troilus	6a	22b	41c	39c
Phytocoris antennalis	0a	6b	10c	12c
Pollenia sp	0a	0a	12b	11b
Rhizophagus remotus	0a	5b	10c	10c
Scudderia sp	3a	6b	11c	12c
Stethaspis sp	0a	5b	14c	15c
Strachiini sp	0a	0a	10b	11b
Tenodera	2a	4b	15d	10c
Tipula colei	3a	9b	21c	19c
Triepeolus lunatus	0a	20b	42d	39c
Non-flying fauna				
Camponotus floridanus	14a	17a	39b	36b
Lophocampa sp	4a	11b	30c	28c
Lopidea sp	3a	4a	11b	12b
Metaparia viridimicans	3a	4ab	6bc	7c
Reticulitermes sp	11a	22b	37c	38c
Ummidia sp	2a	9b	22c	23c

L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. Means in the same row that are followed by the same letter do not differ significantly, p = 0.05, Duncan's Multiple Range Test, n = 4.

Coenosia sp was not influenced by liming, probably because it could inhabit wide range of flora species (Maneepitak, 2007). Interestingly, *Culiseta* sp decreased with increase in liming. This trend probably indicated that their preferred flora for hide out or breeding may have declined upon liming; this, however, needs verification through further research.

Table 13 shows the effect of liming on fauna abundance, richness and eveness. Species abundance, richness and eveness increased with increase in liming from L0 to L2 and no further significant increment was noted. Higher abundance, richness and evenness registered for fauna than flora was due to mobility characteristic of fauna (Ryder, 1986). In line with this, fauna such as flies could be attracted from other ecologies en route to limed plots where they could find their interests (meal or shelter) (Maneepitak, 2007). This explains how liming managed to improve both the flora and fauna diversity index scores of the treated plots.

Table 13: The abundance, richness and evenness of fauna species nine months after liming

	Treatment means (*counts*)			
	L0	**L1**	**L2**	**L3**
Abundance	218a	372b	701c	699c
Species richness (S)	21a	26b	30c	30c
Evenness (J)	0.68a	0.89b	0.95c	0.95c

L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. Means in the same row that are followed by the same letter do not differ significantly, p = 0.05, separated by Duncan's Multiple Range Test, n = 30.

4.6.2 Below ground biodiversity

Plate 10 show bacteria colony forming units in L0, L1, L2 and L3 treatments. This represented the general findings that were observed in soil micro fauna. L2 and L3 had most colonies followed by L1 while L0 had lowest number of colonies. More colony forming units in plates from treated plots were probably due to soil liming, which may have created favorable soil conditions (Boyer and Mahaney, 1985), such as reduction in Al and Mn toxicity. Bacteria remained the most abundant in the soil nine months after liming mainly because of expected higher populations of bacteria in the soil (Department of Crop and Soil Sciences, 2004).

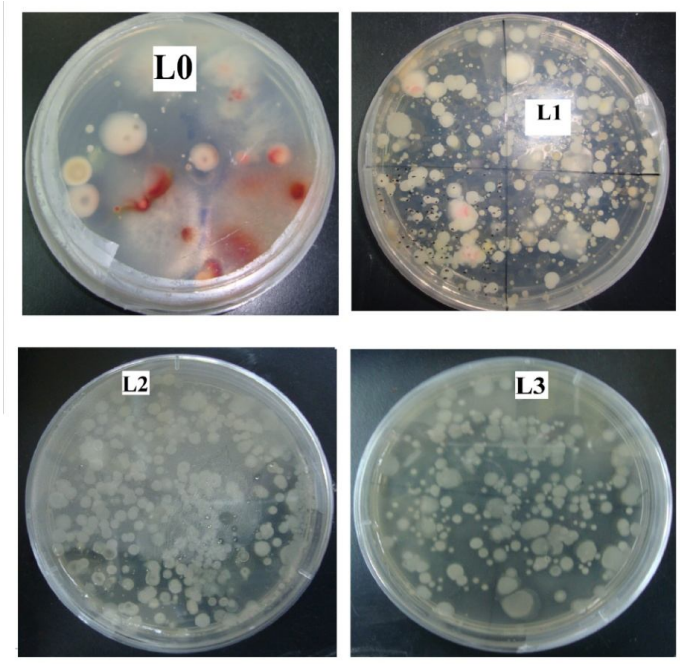


Plate 10: Bacteria colony forming units from the soil sample nine months after liming.
L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. The clusters seen on petridishes are the colony forming units (cfu) of the bacteria. The plates show cfu increased with increase in liming from L0 to L3.

Table 14 shows counts of bacteria and fungi colony forming units in the soil, nine months after liming. Treated plots had significantly higher frequencies of microorganisms probably because liming reduced H^+ that are known to interfere with the electrochemical gradient between the inside and outside of the cell (Boyer and Mahaney, 1985). The more the liming from L0 to L3 the higher the quantities of microorganisms and their biodiversity, corresponding to Helyar et al., (1994; 1997) finding that liming improved the growth of microorganisms.

L3 showed highest percentage increase for bacteria while for fungi there was no significant difference between L2 and L3. This probably indicated that fungi could thrive on lime levels L2 and L3 equally and without notable disturbance. Douglas and Lingenfelter, (1995) had noted that some soil organisms have wide range of favourable soil conditions, giving an idea that fungi was among such soil organisms.

Diversity (H') in soil for fungi and bacteria indicated that there was no difference between L2 and L3 but the two differed significantly from L1 and L0. This implied that liming may have made soil environment conducive for more organisms (Helyar et al, 1994; 1997).

Table 14: Bacteria and fungi colony forming units in the soil nine months after liming

	Bacteria	Fungi	H'
	cfu x 10^5 g^{-1} soil.		
L0	19a	7a	0.58a
L1	23b	11b	0.63b
L2	48c	39c	0.69c
L3	64d	42c	0.67c
Means	38.5	24.8	0.64
CV (%)	5.53	7.39	7.56

L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. cfu – colony forming units, H' – Shannon diversity index. Means in the same column that are followed by the same letter do not differ significantly, p = 0.05, separated by Duncan's Multiple Range Test. n = 4.

Table 15 shows the nine months effect of liming on soil meso and macro fauna quantities in the soil. Nematodes appeared unaffected by liming. The frequencies in all the treatments were almost uniform. Probably, this was because nematodes only need little Ca and Mg to live well and they may have adapted to acidity as well. This concurred with Boyer and Mahaney (1985) who noted that an increase in the proportion of hydrogen ions in the soil, affected aspects of micro organism life such as bacterial but not meso organisms such as nematodes.

Table 15: Soil meso and macro fauna population in the soil nine months after liming

Treatments	Nematodes	Earthworms	Millipedes	Slugs	Snails	H'
	(counts/100cm^3)					
L0	31	8a	14a	16c	15c	1.17a
L1	30	15b	12a	14b	12bc	1.19b
L2	34	21c	13a	11a	10ab	1.22d
L3	33	25d	14a	10a	8a	1.20c
Means	32.0	17.3	13.3	12.8	11.3	1.20
CV (%)	13.3	14.6	12.5	21.6	26.5	1.7

L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. H' – Shannon diversity index, means in the same column that are followed by the same letter do not differ significantly, p = 0.05, separated by Duncan's Multiple Range Test.

As indicated on (Table 15), large soil organisms (macro fauna), tended to increase with increase in liming. This was probably because the organisms could feed directly on lime material hence benefiting from Ca and Mg, that lime had (Mitchell, 1999). Liming increased earthworms in the soil significantly with L3 providing the highest increase probably due to reduction in acidity. This agreed with findings by Baker et al., (1996) and Van Gestel and Hoogerwerf, (2001) that too low pH hinders the increase in earthworms. The increased activities of soil organisms such as earthworms, may have softens the hardpan in the soil (Nuria et al., 2008) hence reducing the soil bulk density.

Ants benefited from lime as it added Mg and Ca nutrients to their food (Black and Okwakol, 1997) explaining why they increased with liming. Millipedes were unaffected by the liming. Slugs and snails decreased significantly in the soil upon liming. This was probably due to liming which is speculated to deter snails and slugs (Boyer and Mahaney, 1985).

4.7 The relationship between biodiversity (flora, above ground fauna, soil micro, meso and macro fauna) and soil liming

The biodiversity index score increased upon liming (Figs. 11 and 12). Biodiversity in L2 and L3 recorded continuous increase from liming inception to nine months while in L1 it increased up to sixth month before registering a slow decline. Notably, the difference between biodiversity in L2 and L3, with L2 being higher, appeared largest in the 6^{th} month before reducing in the 9^{th} month. Scientists have observed that too much abrupt change is not very beneficial for biodiversity (Turner et al., 2003), perhaps explaining why L3 was not very favorable for biodiversity compared to L2. However, further research is needed to clarify this.

Biodiversity relationship with lime levels from the beginning of the experiment to nine months, assumed polynomial regressions (Fig 12). This indicated that the lime effects in L2 were diminishing faster than in L3, hence reducing the difference in biodiversity between L2 and L3 by 9^{th} month. This was probably the subject of the amount of lime applied (Mitchell, 1999). Biodiversity in L1 did not rise as high as L2 and L3 probably because the amount applied was not enough to neutralize much of the acidity problems compared to amount applied in L2 and L3. This can be supported by Mitchell (1999) findings that the rate of neutralizing acidity using lime depends on the amount applied. Biodiversity in L0 did not increase at all; indeed, it even had a negative gradient (-0.40x). The gradual increase in biodiversity after liming was probably due to slow solubility associated with lime (Mitchell, 1999). Biodiversity in L1 stopped increasing after sixth month probably indicating that much of the applied lime had been exhausted by 6^{th} month. Biodiversity in L2 and

L3, where applied lime was more by weight, 6t/ha and 8t/ha, respectively, continued increasing even in the ninth month. It was at the ninth month however, that the biodiversity was most steady following the experiment, hence agreeing with Turner et al., (2003) that the stability of biodiversity has a time dimension.

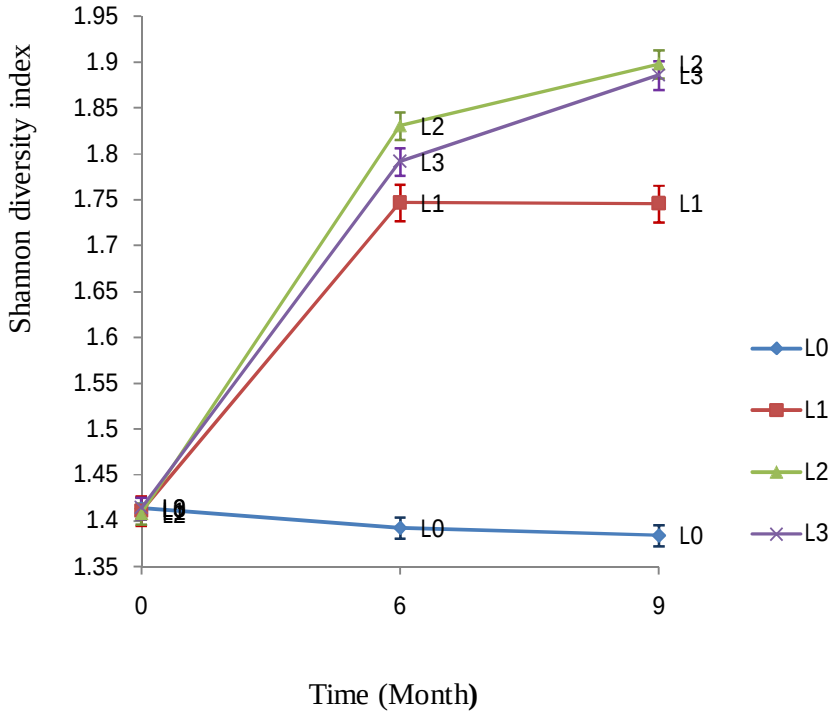


Figure 11: General diversity of flora and fauna in L0, L1, L2 and L3 over a period of nine months in Kavutiri.
L0 = 0t/ha, L1 = 2.4t/ha, L2 = 6t/ha and L3 = 8t/ha. Bars following each lime level along the time indicate the standard error deviation.

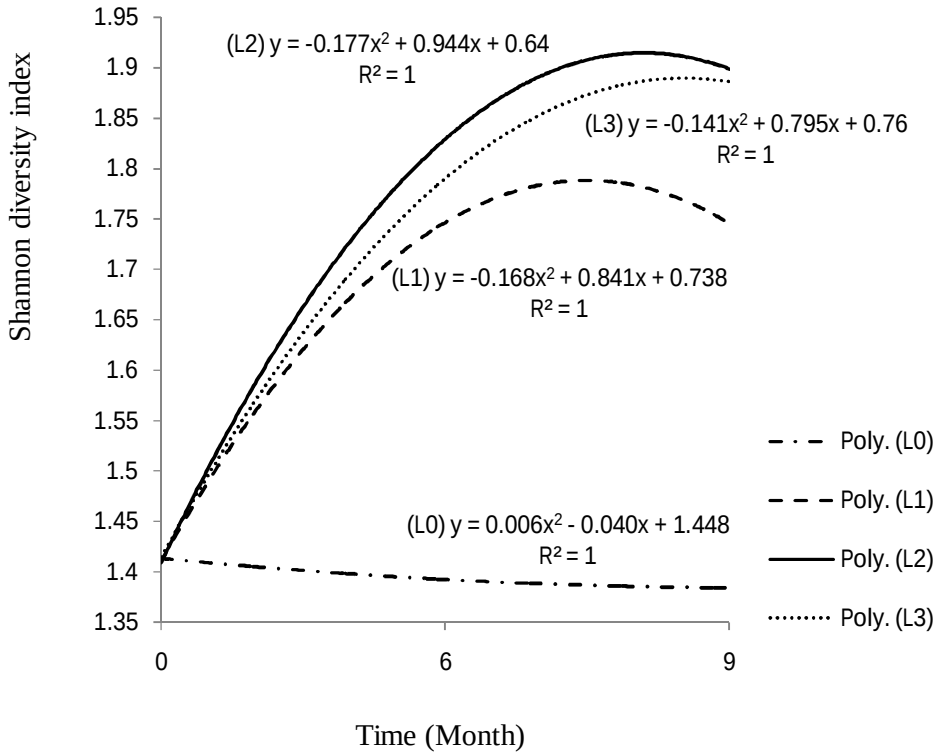


Figure 12: Transformed trend of general biodiversity over a period of nine months in Kavutiri

CHAPTER FIVE

5.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

5.1.1 Soil physical and chemical properties

The liming material that was used in the experiment contained CaO and MgO but they were in unequal proportions (47.4% and 18.5%, respectively) hence, according to Brett et al. (2005), it could be classified as dolomitic limestone. When applied at 2.4t/ha, 6t/ha and 8t/ha, this liming material increased the pH of the soil by 11.9%, 33.3% and 40.4%, respectively. After liming the Ca and Mg in the soil increased by 42.8% and 56%, respectively for lime rate 8t/ha while lime rate 6t/ha caused increase of 32.1% and 48% for Ca and Mg, respectively. These increments were associated with lime since the two nutrients (Ca and Mg) were the main components of lime (Lindsay, 2001). Liming also lowered exchangeable Al^{3+} in the soil by 24% for 8t/ha and 22.7% for 6t/ha. This reduction was associated with formation of aluminum hydroxide which is less soluble at higher pH. Mitchell, (1999) noted that a pH higher than 5.5 would cause Al^{3+} to form hydroxides. In the experiment, lime rates 6t/ha and 8t/ha resulted in pH 5.6 and 5.9, respectively. Al and Mn reduced in the soil following logarithmic regression, $R^2 = 0.867$ and $R^2 = 0.992$, respectively. On the other hand, Ca and Mg increased exponentially $R^2 = 0.956$ and $R^2 = 0.927$, respectively, while phosphate had a polynomial increase in the soil $R^2 = 0.999$. These regressions were expected since lime is known to cause various reactions in the soil that change status of other elements (Harter, 2007). The exponential increment in Ca

and Mg upon liming confirms that lime indeed supplied Ca and Mg into the soil (Douglas and Lingenfelter, 1995).

5.1.2 Frequencies of flora and fauna species

Liming increased the frequency of flora by 58.8% and 60.6% for 6t/ha and 8t/ha, respectively, basing on flora abundance. Flora increased by 78.6% for both 6t/ha and 8t/ha basing on species richness. These increments could be explained by the liming influence on plants nutrients. Earlier studies revealed that liming enables deficient nutrients in acid soils such as Ca, Mg and P to be available (Gordon, 1999). On the other hand, toxic levels of aluminum ions that could harm the plant roots (Yamamoto et al., 2006), are reduced thereby resulting in high frequencies of flora.

The frequencies of the above ground fauna species were found to be influenced directly by the flora rather than lime. Soil liming was therefore affecting above ground fauna species indirectly through its influence on flora. Higher flora species frequencies resulted in higher fauna species frequencies. However, below ground fauna was found to be influenced by the liming directly. Bacteria, fungi and earthworms were prominently influenced by liming. Bacteria cfu increased from L0 to L3 by a ratio of 1: 3, fungi increased by 1: 6 while earthworms increased by 1:3. These results are related with the findings by Helyar et al, (1994; 1997) that liming improves populations of soil organisms. The results also concur with Douglas and Lingenfelter, (1995) that liming benefit organisms like Rhizobia with Ca hence increasing their populations. Boyer and Mahaney, (1985), on the other hand mentioned how acid soils limits growth of earthworms probably indicating that reducing acidity may have favored their frequencies in the soil.

5.1.3 Relationship between biodiversity and soil liming

The more the liming the higher was the biodiversity. In L2 and L3, where applied lime was more by weight, 6t/ha and 8t/ha, respectively, biodiversity continued increasing even in the ninth month. It was at the ninth month however, that the biodiversity was most steady, agreeing with Turner et al., (2003) that after any disturbance the stability of biodiversity requires time.

Biodiversity relationship with lime levels from the beginning of the experiment to nine months was polynomial with statistical regressions: L0, $R^2 = 1$; L1, $R^2 = 1$; L2, $R^2 = 1$; L3, $R^2 = 1$. This relationship is related to what other scientist have found out about factors that lower biodiversity. Susan and Fahrig, (1995) noted that acid soils favors few species, hence low diversity. Reducing the acidity therefore would mean creating more favorable conditions for organisms to survive, thus increasing biodiversity. Similarly, Georgina et al., (2005) noted that acidity mainly leads to increased levels of aluminum and manganese available to the plant, causing toxicity damage to sensitive flora and fauna. This lowers the diversity. Reducing the acidity would be expected to increase biodiversity. In both cases of Susan and Fahrig, (1995) and Georgina et al., (2005), it would be expected that the higher the liming, the higher the diversity.

5.2 Conclusions

Following the experiment and at 95% confidence limit, the first null hypothesis that stated; “no acidic soil physical and chemical properties changes due to liming” was rejected because there were notable changes in Al, Mn, pH and phosphate. Lime rates 2.4t/ha, 6t/ha and 8t/ha, increased the pH of the soil by 11.9%, 33.3% and

40.4%, respectively. Liming increased Ca and Mg in the soil by 42.8% and 56%, respectively for lime rate 8t/ha while lime rate 6t/ha caused increase of 32.1% and 48% for Ca and Mg, respectively. These increments were associated with lime since the two nutrients (Ca and Mg) were the main components of lime (Lindsay, 2001). Liming also lowered exchangeable Al^{3+} in the soil by 24% for 8t/ha and 22.7% for 6t/ha.

The second hypothesis that stated; "no frequencies of flora and fauna species resulting from soil liming" can be rejected and instead conclude that indeed soil liming would result in higher frequencies of flora and fauna in acid soils. The more the liming the higher was the biodiversity. In L2 and L3, where applied lime was more by weight, 6t/ha and 8t/ha, respectively, biodiversity continued increasing even in the ninth month. It was at the ninth month however, that the biodiversity was most steady, agreeing with Turner et al., (2003) that after any disturbance the stability of biodiversity requires time.

The third hypotheses that declared; "no relationship between soil liming and biodiversity in acid soil" can as well be rejected and an alternative be; biodiversity increases with increase in liming in acid soils. The lime level of 6t/ha, which had also in the earlier studies contributed to higher maize and bean crop yield (Mugai et al., 2006), resulted in promising biodiversity output in acid soil of Kavutiri.

The overall conclusion was that, the experiment revealed the existence of a relationship between biodiversity and soil liming in acid soils, the more the liming the more the biodiversity. 6t/ha and 8t/ha provided the highest biodiversity. Although the biodiversity in 8t/ha did not significantly deviate from that of 6t/ha, it was

economically cheaper to apply 6t/ha compared to 8t/ha. Therefore, the 6t/ha should be used for increasing the diversity of flora and fauna.

5.3 Recommendations

A further study is required to explore more rates of lime and their effects on biodiversity to determine the optimum liming level for acid soils. The experiment was based on experimental scale of 4 m^2 per plot; it is recommended that a large landscape scale be explored to determine what would be the effect of liming on biodiversity. In this experiment, plots were ploughed and managed to simulate farmers practice, it would be appropriate to apply lime on undisturbed land and determine the biodiversity. Impact of liming on biodiversity in farmlands with different farming practices as well as cropping history should also be explored to determine whether they exhibit similar relationship with the one found in this study.

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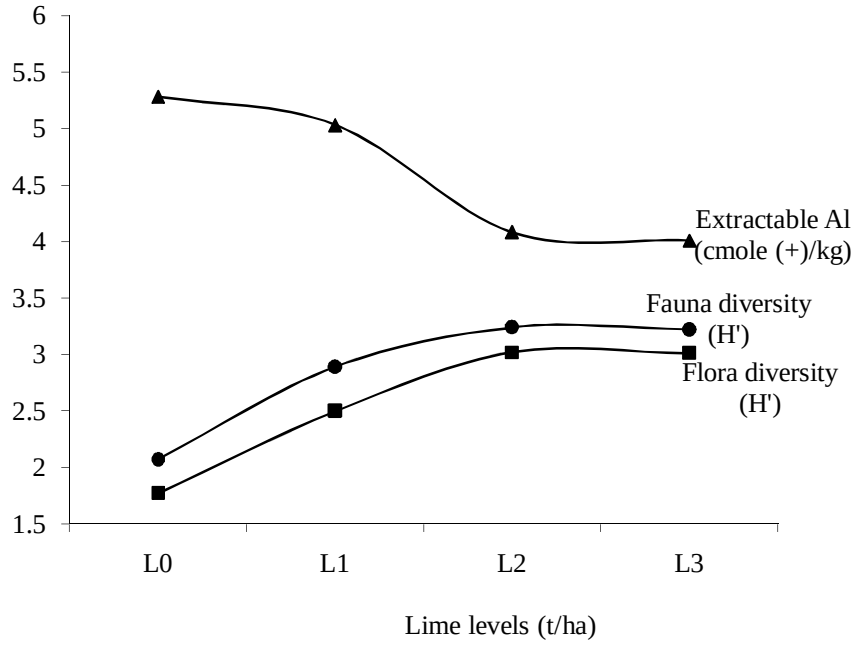
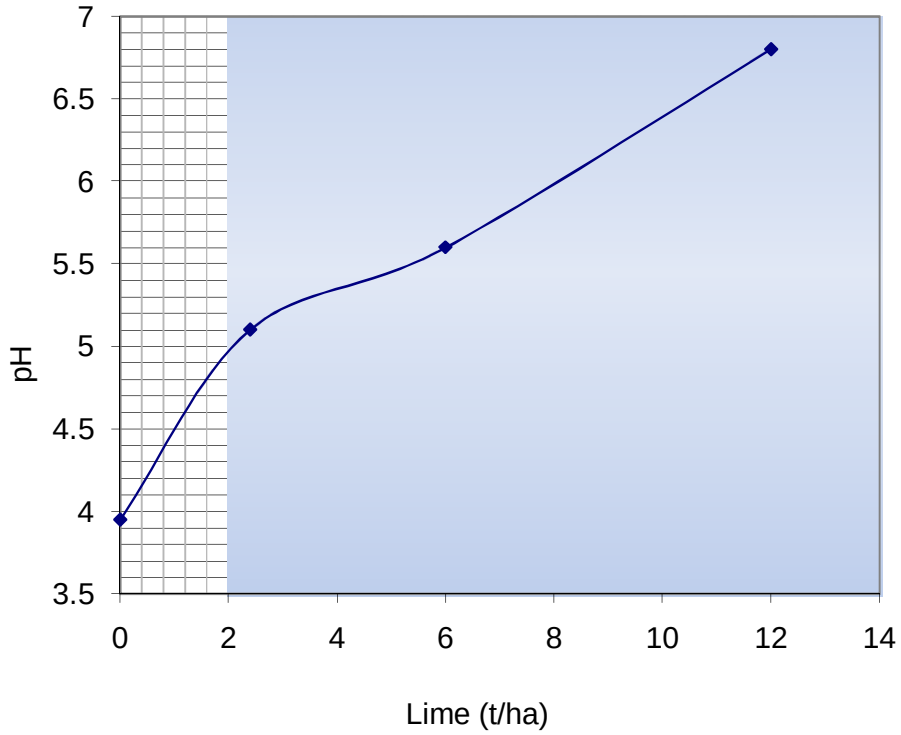
LIST OF APPENDICES

Appendix 1: ANOVA table for soil chemical and physical properties 9 months after liming.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Treatments	115.24	3	38.41	5.57	0.001178	2.66
Soil properties	87484.69	12	7290.39	1056.70		
Interaction	12409.27	36	344.70	49.96		
Within	1076.27	156	6.90			
Total	101085.5	207				



Appendix 2: Relationship between fauna and flora diversity and Exchangeable Al



Appendix 3: Lime calibration curve

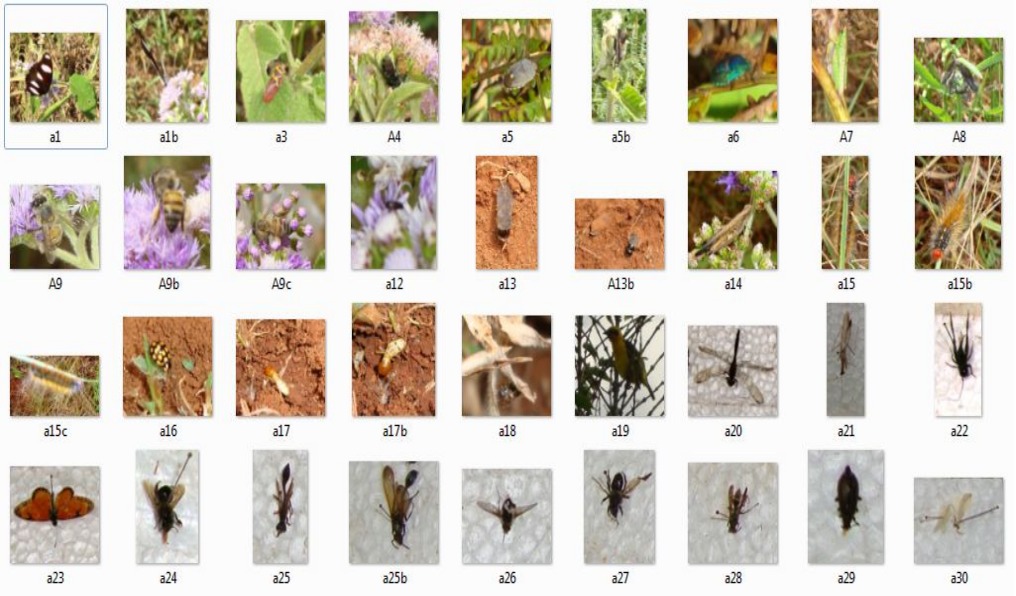
Appendix 4: Conversions of t/ha into kg/16m^2

Lime levels	Rates			
	t/ha	Kg/m^2	g/m^2	Kg/16m^2
L0	0	0	0	0
L1	2.2	0.22	220	3.52
L2	6	0.6	600	9.6
L3	8	0.8	800	12.8

Appendix 5: *Pteridium aquilinum* dominating the experimental site.
A photograph taken from experimental site in Kavutiri before laying out the treatments shows *Pteridium sp.* and *Ageratina sp*. dominated the site.

Appendix 6: Staff posing after site assessment.
From left Dr. E. Mamati, Prof. G. Njoroge, Dr. E. Njue and Prof. A. Nyende; posing on a land that had been left fallow for two seasons following excessive soil acidity.

Appendix 7: Flora domination six months after liming
L0 (control) showing low flora domination comparing to L2 limed plot.



Appendix 8: Some of the fauna from the experimental site before identification

Appendix 9: Some of the flora from the experimental site before identification